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ABSTRACT

This report contains a collection of papers on the status of the use of calculators in the schools of 16 countries. Each report summarizes trends and prevailing opinions about curricular implications of calculators; research activities; instructional practices; student attitudes; in-service activities; and general background on amount and type of use, projects, and other concerns. Also included are a synthesis of these national reports and a report of the International Working Group on Calculators from a meeting in January 1980. The report concludes with a list of selected references. The hope of the authors is that this document will answer some of the questions about the current status of calculator use for the following countries: Australia, Austria, Belgium, Brazil, Canada, Hong Kong, Ireland, Israel, Japan, New Zealand, Sweden, Switzerland, Thailand, United Kingdom, United States, and West Germany. (MP)

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INTERNATIONAL CALCULATOR REVIEW

Working Paper on

Hand-held Calculators in Schools

prepared by

Marilyn N. Suydam

for the

Conference on Comparative Studies in Mathematics Curricula
sponsored by the Institut für Didaktik der Mathematik

in cooperation with the

Second International Mathematics Study
International Association for the Evaluation of Education Achievement (IEA)

March 1980

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Introductory Note

A draft of this report was presented and discussed at the Conference on Comparative Studies in Mathematics Curricula, held in Osnabrück, Federal Republic of Germany, in January 1980. The Conference was hosted by the Institut für Didaktik der Mathematik (IDM), Universität Bielefeld, with H. G. Steiner serving as coordinator, in cooperation with the Second International Mathematics Study, International Association for the Evaluation of Education Achievement (IEA).

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Table of Contents

		Page
I.	Introduction	1
II.	National Reports	4
	Australia	5
	Austria	9
	Belgium (Flemish)	13
	Brazil	16
	Canada	19
	Hong Kong	25
	Ireland	28
	Israel	31
	Japan	34
	New Zealand	39
	Sweden	42
	Switzerland	45
	Thailand	51
	United Kingdom	54
	United States	60
	West Germany	67
III.	Synthesis of National Reports	71
IV.	Report of the Working Group	81
V.	Selected References	88

Working Paper on

HAND-HELD CALCULATORS IN SCHOOLS

I. Introduction

In the late 1940s, the modern computer was developed; by 1960, its impact was being felt in a range of industrial, commercial, governmental, and even educational applications. In the 1970s, the computer affects the daily lives of most people of the developed countries; to a lesser extent, it affects the lives of some proportion of the population in developing countries. Nevertheless, many persons fail to recognize the often covert impact of the computer on their daily activities, as it handles tasks ranging from traffic control to inventory analysis, from information retrieval to banking transactions. The computer remains an unseen, intangible force. The advent of small, personal, home computers within the past few years suddenly has the potential for making the power of computers visible to many who had not been aware of their existence.

In the 1970s, the markets of the world acquired another even more visible computational tool -- a tool that each person can hold in his or her hand. The calculator was one of the first technological developments for consumer use which used the microprocessor; a small chip enabled computing capability to be readily available to all. The technology was rapidly incorporated into numerous devices ranging from clocks and watches, to microwave ovens and washing machines, to cameras and cars. Some of these devices require programming skills of some type; others are preprogrammed, such as the games in which the player interacts with the machine, or the drill-and-practice machines presenting arithmetic combinations for the user to answer.

Almost simultaneously, applications of television-oriented technology were marketed, including video games, videotape recorders, and, more recently, videodiscs. Undoubtedly, the reader can think of other technology which is affecting people's lives, either during work or during leisure time. But the purpose of this paper is to consider the impact of this technology on the schools, on curriculum and instruction. Consideration of how the schools have begun to cope with technological change may provide insights on how to help them adjust to future changes.

Computers are available for some type of student use in, at most, 50 percent of American schools; data are not readily available, but it may be that the percentage in, for instance, the United Kingdom, is slightly higher. In most countries, the percentage is almost without doubt lower. Costs and lack of teacher preparation have been the two factors which have kept the use of computers for educational purposes at this level. Most of the use of computers is in secondary schools, in a problem-solving mode. Tutorial computer-assisted instruction has virtually floundered on one major problem: few persons know how to program the computer to teach immaginatively and effectively.

Television sets have been available in schools since the 1950s, yet only rarely are they turned on in most classrooms. It is partly, but not entirely, a lack of appealing and effective materials: there is also a reluctance on the part of many teachers to incorporate technology, with its special demands, into the chalkboard-and-textbook-oriented classroom.

This same reluctance is evident as the use of hand-held calculators became possible and feasible. One difference should be noted, however: advocates and opponents quickly took opposing positions on several questions. Thus, the use of calculators quickly became, and remains, an emotionally oriented issue. While not a panacea, evidence indicates that calculators can be used to promote mathematical learning and achievement; yet a vocal segment of the population remains opposed to their use in schools, at least until all arithmetical skills have been mastered using traditional paper-and-pencil methods.

The controversial issues regarding the use of calculators in schools largely concern three questions:

- At what levels should calculators be used?
- How should calculators be used -- as computational tools and/or as instructional aids?
- Should calculators be used on tests?

Of lesser concern are the problems which arise from the need for the training of teachers and the development of curricular materials to integrate the use of calculators into instruction. Yet it is with these latter two points that the burden of successful acceptance of new technology actually lies.

To assess the current status of activities and concerns with calculators in various countries -- and, in particular, the countries involved in the

Second International Mathematics Study --, the International Working Group on Calculators was formed. One part of the task is to develop assessment instruments to be available on an optional basis to countries involved in the International Study. Another part of the task is to ascertain the existing situation. The individual reports from various countries which follow provide comments on each of the issues expressed in the previous paragraph. The persons preparing the reports were asked to summarize the status of calculator use in schools in terms of:

- Trends, predictions, and prevailing opinions about curricular implications of calculators
- Research activities with calculators
- Instructional practices
- Student outcomes, attitudes, and concerns
- In-service activities for teachers
- General background on amount of use, type of use, projects, etc.

Reports from 16 countries are included as Part II of this working paper. Comments synthesizing these national reports are presented in Part III. In part IV is a report of the working group from a meeting in January 1980. Finally, a list of selected references is to be found in Part V.

We hope that this document will answer some of the questions about the current status of calculator use in a number of countries around the world.

II. National Reports

As noted on the previous page, this section includes reports on the use of calculators in schools prepared by persons in 16 countries:

- Australia - A. L. Blakers
- Austria - W. Dörfler
- Belgium - G. Plancke-Schuyten
- Brazil - Ubiratan D'Ambrosio
- Canada - Walter Szetela
- Hong Kong - Y. L. Cheung
- Ireland - J. J. Kelly
- Israel - Gideon Zwas
- Japan - Shigeru Shimada
- New Zealand - B. W. Werry
- Sweden - Ove Hemer
- Switzerland - P. Knopf
- Thailand - Samrerng Boonruangrutana, Patrakoon Jariyavidyanont, Nongnuch Watanawaha, and Rungtip Loakhom
- United Kingdom - David S. Fielker
- United States - Marilyn N. Suydam
- West Germany - Hartwig Meissner

[It should be noted that other countries participating in the Second International Mathematics Study were asked to supply reports, but none were forthcoming (for unspecified reasons).]

Calculators in Schools in Australia

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University of Western Australia

Australia became a single nation in 1901 by the federation of six states and the inclusion of a number of territories -- regions too sparsely populated to be viable as separate states. In terms of the Australian constitution, education is the responsibility of the states, and this has to be understood in any consideration of educational matters in Australia. One result is that, notwithstanding a recent tendency to devolve educational responsibility to regions and even individual schools, there is a significant degree of homogeneity within each state. Another consequence is that any generalisation concerning education in Australia is likely to have exceptions. In the preparation of this paper, I have been assisted by a number of correspondents from other states, and as a result I believe that this represents a fair statement of the current and recent history of the impact of calculators on Australian schools.

When hand-held calculators first became available in Australia about seven years ago, they were quickly acquired by working scientists, engineers, economists, and other professionals. There was no immediate realisation that costs would fall fairly rapidly and that both simpler and more sophisticated models would soon begin to proliferate. During 1975 and 1976, both individual teachers and education systems began to realise that they would have to come to terms with the calculator, and that process of adjustment is still under way.

Calculators appeared first in individual classrooms, as the property of the teacher, and in individual homes, where a parent had a professional need or a fascination with gadgetry. By about 1976, prices had fallen sufficiently that they had become popular birthday and Christmas gifts, and teachers began to face the dilemma of the extent to which their use would be permitted in the classroom. About the same time, mathematics coordinators, superintendents, and curriculum officers in state educational systems began to consider how calculators might be used in the classroom to enhance the teaching of various subjects, especially those which necessitated a considerable amount of arithmetic calculation. Circulars to schools at this time disclose a cautious approach, including advice on the potential and differences in particular instruments, as well as

suggestions on the specific use of calculators. Some schools began to purchase calculators for school use, much as schools would provide such scientific equipment as balances and microscopes.

In the subsequent development of calculator use in Australia, one important feature of the Australian educational scene should be explained. Traditionally, all states have had some sort of public examination at the end of Year 12, leading to a School Certificate, and also used in relation to matriculation and admission to the universities and other post-secondary institutions. In almost all states such examinations still exist. By 1977, the availability of relatively inexpensive calculators and their spreading (but largely uncoordinated) use in schools was at a level where matriculation examiners began to recommend that students be permitted to use hand calculators in the public examinations. Approval was not immediately given, partly because the cost was then sufficiently high that it was considered unfair to permit the use of an aid which might not be available to all candidates. As prices continued to fall, this argument became increasingly irrelevant, and by 1980 virtually all examining boards will permit the use of calculators. In some states the choice is unrestricted, while in others there is some limitation designed to avoid the sort of advantage which might result from possession of a sophisticated (and still fairly expensive) programmable calculator.

Once the use of calculators has been approved for Year 12 examinations, it has been inevitable that all Year 12 students (and, increasingly, those in the immediately preceeding years) would obtain and use a calculator. For classes in such subjects as physics and chemistry, calculators have simply become a part of the student's equipment, replacing slide rules and tables of logarithms and functions, and making it possible to use more realistic numbers in various problems. For the mathematics classes, there has been a more systematic consideration of how calculators might be used, not merely to carry out calculations which would have arisen in the past, but also to attack new types of problems, or old types of problems in new ways. For example, it has been argued that an appreciation of the concept of function can be greatly enhanced by calculating values of a wide variety of functions; and the process of improving the solution of an equation by calculating values in the neighbourhood of an approximate solution has become commonplace.

Australian teachers have access to professional journals published in other countries, and it is safe to say that many ideas for the use of

calculators in the improvement of Australian mathematics teaching have originated elsewhere. Some such ideas have undoubtedly been re-invented in Australia. A perusal of the Australian Mathematics Teacher (the journal of the Australian Association of Mathematics Teachers) discloses no articles on this topic prior to 1978, and only one article in Volume 34 (1978). This article by Max Stephens is entitled "Developing Classroom Materials Using Minicalculators". It is a good example of the best of the current thinking in Australia by one of the leaders in school mathematics in his state. In the period 1976-79, the same journal has a number of articles on computers and their relationship to school mathematics, and more recently there is an article on microprocessors; but these are not the subject herein discussed.

It is safe to say that in a year or two virtually every student (certainly every mathematics student) in secondary school will have (and use) a calculator. Undoubtedly the relationship of this fact to the need for individuals to preserve a reasonable arithmetical facility will continue to be argued and some accommodation will be reached. However, the debate on the pros and cons of the further spread of calculators into the primary level will surely continue, and its outcome is not at all obvious at this stage. Some primary teachers and curriculum officers are experimenting with the use of the calculator as a learning aid, and of course many primary children are being introduced to calculators by their parents or their older siblings. I am unaware of any current plans (in any state) to formally introduce the use of calculators into the primary school curriculum, but it seems reasonably certain that the next few years will result in significant changes in this area. Scheduled for publication is an article by Anthony J. Koop of Macquarie University, entitled "The Calculator Revolution: Potential Roles for Elementary Teacher Educators".

There does not appear to have been any major problem so far in preparing teachers for the advent of calculators in the classroom. As mentioned earlier, educational authorities have prepared circulars for schools. In addition, educational authorities have run short (frequently half-day) inservice programs for teachers, on the use of calculators; and professional organisations (such as branches of the Australian Association of Mathematics Teachers) have sponsored seminars and discussions in which practising teachers have exchanged experiences.

In summary, the position in Australia is decidedly fluid, but the experience does not appear to be very much different (except for a possible time lag) to what it has been in other countries with similar attitudes to education and with comparable levels of economic development.

References

Koop, Anthony J. The Calculator Revolution: Potential Roles for Elementary Teacher Educators. To be published in Australian Mathematics Teacher.

Stephens, Max. Developing Classroom Materials Utilising Minicalculators. Australian Mathematics Teacher 34: 129-140; October 1978.

Calculators in Secondary Schools: Guidelines. Education Department of South Australia, December 1978.

Some Guidelines for Selecting and Testing a Minicalculator. Education Department, Secondary Schools Division, Melbourne, March 1978.

Some Proposals for the Use of Minicalculators in Mathematics. Education Department, Melbourne, September 1978.

Calculators in Schools in Austria

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The greatest difficulty in developing this report was the fact that there does not exist any centrally organized inquiry on the status of the use of calculators in Austrian schools. So even the competent ministry of education was not able to give any information about this topic. Therefore several schools, pedagogical institutes, and individual teachers were asked to report on their experiences. The data obtained are by no means homogeneous, and the stage of development pertaining to calculators depends to a great extent on the interest and initiative of the individual teachers or of corresponding working groups. From some parts of Austria, no figures on the use of calculators could be obtained.

The school curriculum regulates the use of calculators in the following way: Beginning with the seventh grade, either the calculator or the slide rule has to be introduced as a calculating means. Since the type of school has a great influence on the extent and the form of the use of calculators, it is necessary to give a short description of the Austrian school system. At the secondary level for the ages of 10 to 14, there exists the "Hauptschule" and the lower grades of the "Allgemeinbildende höhere Schule" (the latter is usually called "Gymnasium"). For the ages 15 to 18 or 19, there are available the upper grades of "Allgemeinbildende höhere Schule" and several types of vocational schools (colleges for engineering sciences, economics, and trade). Going to school is compulsory up to the age of 15. Special consideration with regard to the use of calculators has to be given also to numerous experimental schools, especially for the "Hauptschulen".

Concerning the amount of use of calculators, very divergent data were obtained. At the experimental schools of the type "Hauptschule", about 90% of the teachers use the calculators beginning with the seventh grade. In these schools, we have at every grade about 10 000 pupils. For the regular schools of the type "Hauptschule", we have almost the contrary situation; i.e., the calculator is used rather rarely (one figure was that more than 50% of the teachers never use the calculator). The situation is similar in the lower grades of the "Allgemeinbildende höhere

Schulen". In the upper grades of the "Allgemeinbildende höhere Schulen", especially beginning with grade 10, the calculator is widely used (one report shows more than 70%; another, 100%). In the experimental schools of the "Allgemeinbildende höhere Schulen" already in the school year 1975-76 all pupils of grade 10 obtained the calculator, and since then it is used exclusively. At the colleges of engineering sciences ("Höhere Technische Lehranstalt"), the calculator is completely accepted not only in mathematics but also in the technical subjects. At the colleges of economics and trade ("Handelsakademie"), there still exist some problems in introducing the calculator, especially in non-mathematical subjects.

There does not exist any didactical research on the use of calculators in Austria. It is only possible to report on regional inquiries using questionnaires and on statements of teachers. Thereby the following points seemed to be of interest:

Arguments for the use of calculators

- The quality of teaching mathematics in general is increased.
- There is more time available for genuine mathematical content.
- In solving problems the emphasis is shifted from routine calculations to problem-solving strategies.
- It is possible to pose a greater number of exercises and problems with an increased connection to practical situations.
- The calculator supports heuristic processes.
- The pupils like to work with the calculator.
- It is possible to organize discovery learning.
- New subjects like probability and statistics can be introduced, since they can be treated appropriately with the use of calculators.

Arguments against the use of calculators

- The calculating ability of the pupils is decreased and there is a tendency to use the calculator also for very simple calculations.
- There is danger of dependence on the calculator.
- There is a lack of criticism concerning the results delivered by the calculator.
- There is great variety in existing models of calculators.

Didactial means for compensating for negative influences of the calculator

- Continuing exercise of mental arithmetic.
- Training of rounding and considering of rounding errors.
- Making estimates of results and approximate calculations.

- Testing the significance of the exactness of the results.
- Drawing a flow chart before the calculation.
- Conveying the limits of the use of calculators.

Concerning in-service training of teachers, it was reported that there have been organized lectures and seminars by various working groups and Pedagogical Institutes. There were no data available about the contents of these sessions.

The calculator is used mainly in treating the following mathematical content:

Grades 7 and 8: direct and indirect proportionality, calculations with percentages and interest, exercises from the everyday life, decimal numbers, evaluation of graphical representations, equations and inequalities, geometric formulas (area, volume, Pythagorean theorem).

Beginning with Grade 9: functions, trigonometry, exponential and logarithmic functions, convergence of sequences (definition of e), equations, applications of mathematics in physics (exploitation of experiments, thermodynamics.

Throughout all schools, the calculator is used during the lesson at school as well as for solving the exercises at home. Sometimes its use is also allowed for examinations.

Almost all of the well-known models of calculators are used somewhere in Austrian schools. Calculators with algebraic logic are preferred, and about 50% also possess implemented hierarchy. Mostly one or two memories are available. On the calculators for the lower grades, the functions x^2, $\frac{1}{x}$, and $\sqrt{x}$ are available; for the upper grades, also available are sin, cos, tan, exp, log, ln, and x^y. Programmable calculators are not used. The calculators usually are bought by every pupil; sometimes the acquisition is organized by the teachers or by the school.

Summarizing, it should be noted that the introduction of the calculator in Austrian schools proceeds without posing great problems and without extensive discussions. For the time being, there still exist great regional distinctions which are caused by the relative autonomy of the schools and teachers. A main obstacle for intensifying the use of calculators is the fact that neither the curriculum of mathematics nor the schoolbooks are related in any way to the needs and possibilities of

the calculator. This especially concerns the exercises and problems which by the use of the calculator will become too simple because they are intended to train routine calculating abilities and not to train problem solving. It is therefore an important task to make available for the teachers appropriate books and collections of exercises. In this context, it is also clear that, since the introduction of the calculator, no essential change in the contents and method of teaching mathematics has taken place. For such a change it would be necessary to intensify the in-service training of the teachers and to include the use of the calculator in the teacher training at all levels.

Addendum

A recent inquiry (March 1979) organized by the Ministry of Education has shown the following figures for the Allgemeinbildende höhere Schule:

Grade	Percentage of classes using a calculator
7	58.6%
8	57.9%
9	57.4%
10	93.5%
11	94.8%
12	78.8%

Calculators in Schools in Belgium

G. Plancke-Schuyten
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Mainly due to the availability of hand-held calculators for the past four years, mathematics educators in Belgium are interested in using them in schools. Since 1976, articles and conferences have been devoted to the use of calculators at the discretion of the teachers. The panel discussion about calculators at the I.C.M.E. congress at Karlsruhe in 1976 had an impact in Belgium.

To understand the situation in Belgium, one has to be aware of some characteristics of the educational system. The Dutch-speaking and the French-speaking parts of the country are autonomous concerning the curricula. Each part has three kinds of educational establishments (state, free, provincial), each of them having their own curricula. These curricula are, however, very similar so that, in fact, we can speak of one common national curriculum. In spite of this centralization, there is a certain amount of freedom left for the teachers to introduce or try out new activities.

In the existing official curricula, no word is mentioned about calculators, but in the near future it is almost certain that the use of calculators will conquer a place in mathematics instruction. There is still some quarreling going on between two groups, the one stimulating the use of the calculator only as a computational tool and the other willing to take more advantage of calculators as an instructional aid. Some mathematics educators advocate programm' g for those sections of secondary education with a heavy mathematics curriculum, but, in my opinion, considering the official curricula of the three educational establishments, the use of the calculator in the classroom as a computational tool will prevail at all levels of secondary school (ages 12-18).

As to the use of calculators in the primary school, no trend or prediction can be given at the moment. There is a general consensus on the statement that the use of calculators may not replace the learning of computational skills. Related with this statement, there are two extreme, opposite groups. The first is certain that calculators must be banished from elementary schools because their use would have a negative

effect on computational skills. The second group advocates that cautious use of the calculator would have not a negative effect, but rather a positive one on computational skills. At the moment, no prediction can be given about which opinion will prevail.

Research activities are going on at universities in the departments of mathematics and education. Reports of these studies are mainly published in the two journals for mathematics teachers, i.e., Wiskunde en onderwijs (Mathematics and Education), the journal of the Dutch-speaking mathematics teachers' council, and Mathématique et pédagogie (Mathematics and Pedagogy), the journal of the French-speaking mathematics teachers' council. These articles are mostly devoted to the use of the calculator at the higher level of secondary school (ages 15-18) as a computational tool and as an instructional aid. In most cases, the reports have the character of demonstrations.

At the Decroly school, the curricula for the higher level of secondary schools have incorporated the use of programmable calculators. Their use is in agreement with the pedagogical principles of Decroly, namely, the function of globalisation, the use of active methods and the centres of interest. At the experimental school (ages 6-12) of Ghent, State University, research is going on on the use of the calculator as an instructional aid for memorization of the multiplication and division tables for children at the third year (ages 8-9).

As to student attitudes, only personal opinions of the teachers are known. According to them, students are generally in favour of using calculators, especially programmable calculators. Some teachers, although they started activities with calculators with enthusiasm, are disappointed. As they say, some students consider the calculators as magic boxes, but they lose interest in them very quickly when they realize that much thinking is involved in working with them. Much more research is needed about the relation between motivation and the use of the calculator considering psychological variables and mathematics achievement of the students. At this moment no data are available about student attitudes. At the end of 1979, the results of a survey will be known.

The two already-mentioned councils of mathematics teachers have organized seminars for secondary school teachers which were attended by many teachers. At the University of Antwerp and the State University of Mons, working sessions are being organized in 1979 on Saturday mornings

attended at the discretion of the teachers. At the Decroly school also, a seminar is planned. All that is going on concerning in-service training is on a completely free basis, so that the quantity of teachers trained in this way can be considered negligible.

As to the extent to which calculators are being used in schools, there are no data available. In some schools, calculators are forbidden; in others, there is an agreement between the teachers to use them in specific courses and for specific topics; in certain schools, the teacher is completely free in using or not using them. So the situation is rather unorganized and anarchical. At the Decroly school, students in their fourth year of secondary school (ages 15-16) are working two hours per week with calculators, occasionally in the mathematics courses. In the 5th and 6th year (ages 16-18), they use them regularly in the mathematics and physics courses.

In summary, the use of calculators in education is introduced in an unorganized way in Belgian schools. At this moment, there are no data available as to the extent and type of use, or on attitudes of students and teachers. A lot of discussion is going on. In the near future, curricula will be adapted, taking into account the changed situation, i.e., the availability of the calculator.

References

Various articles have appeared in Wiskunde en onderwijs and Mathématique et Pédagogie.

A special issue of Mathématique et Pédagogie is devoted to "La minicalculatrice dans l'enseignement secondaire": No. 11/12, 1977.

A monograph of V.V.W.L. (Council of the Dutch-speaking mathematics teachers) is devoted to calculators: "Algoritmen en zakrekenmachines in het wiskunde onderwijs".

Calculators in Schools in Brazil

Ubiratan D'Ambrosio
Universidade Estadual de Campinas

It is undeniable that hand calculators have a visibility in Brazilian educational scenery, being favoured by some but rejected by many. At the university level, the rejection is mild, generally in the form of being ignored by the faculty. Even disciplines like Numerical Calculus ignore hand calculators and in some cases forbid their use on the ground that they may cause an advantage for students who have economical means to acquire better machines. The fact is that while most university students have hand calculators and utilize them in physics, chemistry, and other disciplines, in the mathematics curricula they are ignored.

In secondary education the situation is basically the same, and in primary education the resistance is stronger.

Common ground for resistance are the classical ones:

(1) Hand calculators will enhance the gap between the haves and the have-nots;

(2) There is no point in talking about hand calculators when the students are poor, to the extent of being inadequately fed;

(3) Hand calculators will severely damage the development of children, making them less capable of intellectual achievement.

Although most of the reaction is verbal, some articles are published, and there is an account of a mayor of a reasonably important industrial center who asked the state governor to submit a law forbiding the use of hand calculators!

Commenting on the objections, which are practically the same all over the world, we may use the arguments which are in general raised by the defenders of hand calculators. First, the gap between the haves and have-nots is a social problem, reflected in hand calculators as well as in books, in health, and in the overall quality of schooling. In fact, this argument speaks in favour of hand calculators, since in job competition the have-nots will be seriously handicapped by not having been exposed, be it in their homes or be it in their schools, to current techniques and equipment which are increasingly required in the job market. We have discussed this elsewhere (D'Ambrosio, 1978).

The second argument is equally imprudent, since we entirely agree that food, health, and other vital factors have absolute priority over not only hand calculators, but also over books and school uniforms. On which grounds can one justify that a child must use a pair of shoes to go to school while we know that this pair of shoes is bought with the with the effect of not eating meat for some months? And on which grounds can we ask a child to bring to the school a notebook and a pencil, knowing that this will mean at least a week without a cup of milk? Of course, priorities have to be examined. But at the moment there is enough justification for a school to require a special pair of shoes, or a cartographic atlas or a dictionary, or a drawing compass, all of them more expensive than currently available hand calculators (steadily priced in Brazil at about the equivalent of US$10.00 for many years, against a rampaging inflation of about 60% per year). I see no support for arguing against the calculators on an economic basis.

With respect to the third argument, on the ground of learning damage, I know of no research supporting this view. On the contrary, all existing research shows that in cases where no advantage has been noticed, no damage has been noticed either. But the amount of research showing positive results in the use of hand calculators in elementary schools is growing, and we will report on some of those investigations carried on in Brazil.

An interesting project was carried on by Maristele P. Polidoro and Maria Teresa C. Mortari (see ATAS 5A. Conferencia Inter-Americana de Educaçao Matematica, 1979) in a lower-class, semiprofessional school, for children 12-13 years old. The results were highly encouraging, showing a full acceptance of electronic equipment by children without previous experience with it. It was also possible to notice an overall improvement, not only in mathematics, of low achievers. Even effects on the general behaviour and self-confidence were noticeable.

In the northeastern state of Piaui, one of the poorest in the country, a project was carried on in the capital city of Teresina, sponsored by the State Secretary of Education. The project was conducted by Mario Lucio da Costa Ferreira, and the results showed again no reaction at all of children with respect to hand calculators. Indeed, the overall results, in many subjects (not only mathematics), showed a remarkable improvement.

The secondary school run by the army, as preparation for the Army Academy, has adopted hand calculators in its curricula, with encouraging results, under a project conducted by Rudy L. Wolff.

The situation in other countries of Latin America is no different. The same arguments are used against the hand calculators. In some cases, in less-developed countries, the argument against hand calculators is reinforced because of an effective lack of availability of low-priced calculators. This is certainly not the case of Argentina, Chile, and Mexico, where low-priced calculators are made and thus are available. But in all cases, the arguments are consistently similar.

A project underway in one of the poorest regions of Argentina, the Provincia del Chaco, should be mentioned. Under the leadership of Carlos Alberto Mansilla and sponsored by the Provincial Secretary of Education to introduce hand calculators in the secondary school, it is based on the grounds of offering better job opportunities for secondary school graduates.

A growing number of experiments tend to gain acceptance for hand calculators in schools. The sales are booming. Imaginative commercials and the appeal of giving calculators as toys in upper-middle-class families will pave the way for widespread presence of hand calculators in schools. This will doubtless require a different attitude of teachers.

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Calculators in Schools in Canada

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The movement toward implementation of calculators as a tool for mathematics learning in Canada has generally been cautious and deliberate. While various individuals and organizations have extolled the merits of calculators as an aid in mathematics learning, fear persists that calculators will reduce motivation and achievement in the learning of basic computational skills. The "back to the basics" movement may be another factor that restrains wider acceptance of calculators in schools.

New ideas have often met with public resistance. An example of such resistance is the negative attitude of many Canadians toward the carefully planned program for replacement of the imperial system of measurement by the metric system. But whereas metrication has been legislated, policies on calculators are left to individual communities. School boards are keenly aware of the objections and concerns of parents toward calculators and hesitate to pursue an uncharted course utilizing calculators without strong public support. A notable exception is the Hamilton, Ontario, Board of Education, which has recommended that student use of calculators be encouraged in all subject fields, including use on tests and exminations. Approval was also given to purchase 20 classroom sets of calculators for grades 7 and 8, and the Hamilton School Board also recommended that a carefully designed and controlled experimental program be developed which is "aimed at improving the concept formation of pupils in the Primary and Junior Divisions." A brief chronology of calculator-related events in a Hamilton report shows a strong calculator thrust in schools through in-service programs, placing of calculators in schools, and experimental projects in schools.

Teachers of mathematics tend to be somewhat more positive about calculators, but the majority of teachers still remain concerned about the basic computational skills. At opposite ends of Canada, Sherrill (1977) in British Columbia and Hawco and McGrath (1976) in St. John's, Newfoundland, have conducted surveys which indicate that teachers view calculators in secondary schools with confidence, but in elementary schools with doubts. This feeling appears to be more pronounced in Newfoundland than in British

Columbia, if the surveys are truly representative samples. Comparable items from the surveys, shown below, may give some idea about this picture of attitudes.

Item 17 from Sherrill Survey:

"Calculators could lead to a complete breakdown in students learning basic skills."

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Primary teachers	0	2	1	7	1
Intermediate	1	3	4	9	7
Secondary	3	15	13	32	11
College/university	1	2	1	2	1
Total	9 (7%)	24 (18%)	20 (15%)	58 (43%)	24 (18%)

Item 7 from Hawco/McGrath Survey:

"Do you think that the extensive use of calculators would result in the loss of basic computational skills?"

Response	Teacher Grade Levels			
	4-6	7-8	9-11	Total
Yes	14 (74%)	14 (70%)	39 (67%	67 (69%)
No	5	6	19	30

In Canada's most populous province, Ontario, the draft curriculum guideline (1977) for grades 7 through 10 discusses shifts in emphasis to practical applications and numerical methods, which naturally leads to the encouragement of the use of calculators in schools. With a focus upon problems in the real world, the guideline states that "students will face problems which do not have numerical simplicity, and calculators will help to simplify tedious calculation enroute to the final solution." The potential for the calculator to expand learning horizons is indicated by statements that calculators "extend the breadth and depth of applications that can be explored," and that "the minicalculator lends itself to discovery exercises." Awareness of the embryonic stage of the use of calculators in schools is shown by the suggestion that "there is a need for

informal research by teachers at the classroom level to establish and evaluate ways of using the minicalculator to investigate many of the traditional topics in the curriculum." Concern that the calculator not be used as a crutch is expressed in the statement that "care must be taken to ensure that students do not rely exclusively on calculators. There is a need to include a variety of experiences that require mental arithmetic and simple pencil and paper calculations."

The general awareness of the potential of calculators in mathematics learning, tempered by concern about possible loss of basic computational skills, is exhibited in the British Columbia Curriculum Guide. The guide states that "hand calculators be used in imaginative ways to reinforce learning and to motivate students", but that "calculators should be used to supplement rather than supplant the study of necessary computational skills."

Generally, calculators are not permitted for use on scholarship examinations, although the Yukon Territory permits them in physics and chemistry examinations. The Alberta Teachers' Association has approved a resolution encouraging the use of calculators in schools and in examinations.

For most teachers and school districts, adjoining calculators to instructional materials geared for pencil and paper is considered too risky. Although mathematics educators are advocating the teaching of decimal fractions earlier because of their affinity with calculators, one can easily understand why teachers would prefer to wait until materials guiding the instruction of decimals at an earlier stage are written. There remains a feeling that there are still too many unanswered questions and that more research evidence about the feasibility of calculators in schools is needed.

Such research evidence is emerging in Canada to add to the rapidly growing body of research on calculators worldwide. At the University of Victoria, encouraging results for calculator utilization have been attained by Vance (1978) in classroom research with superior students. Szetela (1977, 1978, 1979) has engaged in a program of studies of calculators in grades 3 through 10 in which instruction was given to students randomly assigned to calculator and non-calculator groups. The pattern of results, as indicated in the table below, shows that the use of calculators does not diminish performance and may enhance mathematics learning.

Summary of Results of Studies with Calculators in Mathematics: Instruction in Grades 3 through 10 (Each Study of 4 Weeks Duration)

Year of Study	Grades	Unit of Instruction	Number of Students	Nature of Posttest	Calculator Group Mean	Non-calculator Group Mean
1977	9-10	Trigonometry	131	Skills, concepts, problems	9.90	8.85
1978	7	Ratios	44	Skills, concepts, problems	9.25	7.42
				Problem solving*	5.05	2.11
1978	3-7	Problem solving	34	Problem solving*	3.88	2.82
1979	5	Decimals	54	Skills	8.85	8.78
				Concepts	13.85	13.30
				Problems	5.33	5.22
				Problems*	14.74	12.24

* Calculators used on posttest by calculator groups.

Although most of the differences in these studies were not significant, it is noteworthy that the calculator means were higher in every case.

In-service training on calculators for teachers through workshops and conferences does not appear to be as widespread as needed. Articles discussing ideas for using calculators in teaching are now common in journals of provincial teachers' associations, however. A useful compilation of ideas and articles on calculators has been published by the Alberta Teachers' Association (1977).

Publishers in Canada have provided some excellent activities with calculators which can be used effectively by teachers. Many of these activities are on reproducible sheets; for example, Calculator Activities for the Classroom by Vervoort and Mason (1977). An excellent set of activities on 80 cards, called The Workbox, is available from Addison-Wesley Publishers. However, while such materials are spread throughout Canada, it can hardly be said that they are sought by a tidal wave of teachers.

While the picture which has been presented concerning calculators in Canada shows restrained enthusiasm, with a lack of bold projects for implementation of calculators in schools, the situation is probably similar to that in other countries. The prevailing attitude may well be typified by the response of a Director of Curriculum to a question on attitudes toward calculators when he writes:

> There has not been a rash of suggestions with regard to placing the role of the calculator formally within the program of studies; the use of calculators seems to be centered in high school. It has not become an issue. Decisions to allow the use of calculators in schools have been left to the discretion of local school board officials. We have not had any complaints with regard to abuses; good judgment seems to prevail.

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Calculators in Schools in Hong Kong

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Mathematics education in Hong Kong is being steadily affected by the impact of the electronic calculator, which plays an increasing part in our daily life. Its importance is due to two major factors: the speed and accuracy that the calculator can provide as a computational aid and the useful resource that the calculator can provide as a teaching-learning device. In a progressive society like Hong Kong, where the subject of mathematics is highly valued and the overall achievement in mathematics seems to be more satisfactory than many other subjects, and where all children have at least nine years of free and compulsory schooling, the role of the calculator in mathematics education has become a matter of great concern to teachers, students, and the general public.

In the primary schools, the use of the calculator is not formally and widely accepted in the classroom because both parents and teachers fear that the calculator might become a crutch to children of this age range and thus impair the learning of the basic computational facts and skills. There is still a lot to be done to promote a better understanding of the calculator both as a computational tool as well as a teaching-learning device, and to encourage more widespread use of the calculator in the classroom, with proper control by the teacher so that pupils will not become overdependent on its use.

At the secondary level, the stress on treating mathematics as a tool has created a demand for a greater use of the calculator. One reason for the increasing popularity of the calculator at secondary level is that from 1980 on, the use of the calculator will be allowed in the Hong Kong Certificate of Education examinations. Another reason is that pocket calculators in a great variety are available in Hong Kong at reasonably low prices, placing them within the reach of school students. There is also much less objection to the classroom use of the calculator raised by parents and teachers because secondary students in Hong Kong, after six years of concentrated studies of arithmetic in primary schools, can

be assumed to have mastered the very basic skills of computation. There is no need to worry that the calculator will stand in the way of acquiring such skills. In fact, seminars and surveys have indicated that teachers, parents, and students have favourable opinions toward the use of the calculator in secondary schools. The great majority of students in senior secondary classes do own a calculator and feel that they should be allowed to use it in schools and in examinations. It is reasonable to predict that most, if not all, of the candidates will bring their calculators to the HKCE examinations from 1980 onwards.

The calculators commonly used by upper primary and junior secondary students are the simple four-function type, whereas the scientific type is more appealing to senior secondary students. The programmable type is at present sought mainly by sixth form and tertiary students. It has been observed that many students have calculators which are not suitable for many of the mathematical tasks which they are expected to carry out. Some underuse the calculator by confining its use to operations of addition, subtraction, multiplication, and division only, and doing computations in more steps than necessary. Advice on the purchase of calculators and instruction in their use is needed to enable our students to perform computations with the calculator more efficiently.

On the impact of the calculator in curriculum development, the Hong Kong Curriculum Development Committee has recently produced a new mathematics syllabus for use in secondary schools which attempt to incorporate the use of the calculator. Two notable features of this programme are the de-emphasis of the computational use of common logarithms and the addition of some new topics such as the solution of polynomial equations and more statistics in order to capitalise on the use of the calculator. Creative uses of the calculator in a number of topics are also encouraged.

To help teachers acquire a better understanding of the new curriculum and the use of the calculator, in-service courses, workshops, seminars, and conferences have been organised by the Government Education Department, Hong Kong Polytechnic, University Graduates Association of Hong Kong, the Hong Kong Association for Science and Mathematics Teachers, and the School of Education, University of Hong Kong. More courses have been planned to meet further requests by teachers.

With respect to research and development, there is, at present,

very limited on-going activities in research studies, or in experimentation with and development of materials concerning the use of the calculator in mathematics education. Very few results and products have yet emerged, but it might be mentioned here that Hong Kong is involved in the second IEA study on mathematics achievement and that a study of the use of the calculator is an option in the project.

Calculators in Schools in Ireland

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Background and Historical Sketch

Primary and second-level schools in Ireland come firmly under the central authority of the Department of Education. This Department publishes the curricula and detailed syllabi, monitors standards, conducts examinations, and controls finance. Although schools are free in theory to experiment with courses and syllabi, in practice the centralized system of examinations at the second level and the usual social and vocational pressures combine to make such experiments extremely rare.

The calculator arrived almost by stealth on the Irish educational scene. Without prior fuss or discussion, the Department of Education included in the regulations for the Leaving Certificate examinations in 1974 provision for the use of electronic calculators in examinations in Mathematics and Science. This provision was retained in 1975. At about this time the teaching profession suddenly became aware of the possible implications of the use of calculators in examinations, and a vigorous debate began.

Inevitably, the Irish Mathematics Teachers Association (I.M.T.A.) was in the vanguard of the discussion. Articles on the subject were published in the Association's newsletter and (not surprisingly) in the Computer Education Society of Ireland's Newsletter. A subcommittee of the I.M.T.A. was set up to prepare a report on the educational use of calculators for a delegate conference held in Limerick in March 1976. This report was discussed at the conference and its main conclusions were adopted by a large majority. One of the accepted recommendations was that calculators should be allowed in examinations which did not purport to test computational competence (presumably of the human kind!). Thus the way seemed to be cleared for an increasing use of calculators in schools, the setting up of workshops and seminars to discuss the educational advantages and disadvantages, the conduct of research into pedagogical strategy, and all the paraphenalia of an exciting new voyage of educational discovery.

But, such developments were not to be. Public awareness of a possible

social discrimination in the use of calculators in examinations was fanned into life by an article in one of the leading daily newspapers; the Minister for Education became worried, and calculators were banned from the public examinations in 1976. They have been banned since then, although the situation is reviewed each year. Unfortunately, professional discussion came virtually to a halt in 1976.

Arguments

Among the points which were raised in the often feverish debates of 1975-76 were the following:

(1) A thorough study of the effect of calculators on computational skills should be undertaken.

(2) Teaching methods and course content may need to be revised to take advantage of calculator techniques. Among the issues to be faced are:

(a) What skills are basic and essential?

(b) Should more emphasis be placed on developing skill in estimating and approximating, in assessing relevance and accuracy, in treating significant figures and order of accuracy, in extensive use of scientific notation?

(c) At what age should the use of calculators begin to be taught?

(d) In what ways can the calculator be used as an exciting and instructional influence on educationally subnormal and backward children?

(e) Is there a danger of sloppy and inefficient calculation processes becoming the norm through the lazy use of the calculator?

(3) There is an urgent need for adequate teacher training by way of seminars, workshops, and short courses.

(4) A permanent committee of educationalists should be set up to keep abreast of technological and methodological developments and to keep in view the wider field of computers and data processing.

(5) The use of calculators in examinations must be studied in relation to the following problems:

(a) Possible disadvantages suffered by socially and economically derived students.

(b) Standardisation of calculator type.

(c) Type, length, and range of questions set.

(6) The calculator is a teaching aid and as such should be given as favourable consideration as slide projectors, tape recorders, and so forth.

(7) Important modern techniques in numerical methods may be introduced through the use of the calculator. The teaching of traditional topics such as trigonometric, logarithmic, and exponential functions, statistics, convergence, and so on, may be enhanced.

(8) In the final analysis, calculators are an important part of modern life and are here to stay. This fact must be squarely faced by everyone involved in education.

The Present Situation

The absence of calculator topics in primary and secondary syllabi and the banning of calculators in examinations means that students in general are not motivated to acquire and use calculators. Teachers, too, with a few notable exceptions, do not appear to be stimulated to experiment, even in private, with calculators and new computational methods. A few articles, however, have appeared in the Irish Mathematics Teachers' Newsletter, detailing the exploitation of the calculator in such topics as the making of log tables and the solution of trancendental equations.

Some University departments and Colleges of Education have shown active interest in calculator methods and implications, but it appears that no large-scale research is being carried out.

Calculator activity is therefore in a somewhat dormant stage in Ireland at the moment. However, it surely cannot remain so for long. There is evidence of a quickening interest in the use of computers in education. The results of research in other countries, indicating that instead of hindering the development of computational skills the calculator may enhance it, should allay the misgivings of those who viewed the introduction of calculators into the classroom with concern.

Using Calculators in Schools in Israel

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Various educational activities connected with the use of calculators in mathematical instruction were started in Israel as early as December 1973. These initial activities were concerned mainly with the mathematical education in grades 9 through 12, while emphasizing algorithmic thinking. Associated with this, the concepts and principles involved were explored and reinforced in a calculator laboratory.

A small group of interested faculty was formed at Tel-Aviv University, headed by Professors Gideon Zwas and Shlomo Breuer, who published their first book on the subject in 1975. The philosophy of the group was summarized as follows:

> Accumulated experience has shown that early emphasis on algorithmic thinking, augmented by actual computing, is indispensable in mathematical education. The main benefits derived from their use are concretization of abstract concepts, stimulation of creativity, fulfilled involvement, and interplay between theoretical and computational ideas.
>
> Accordingly, we advocate the introduction of mathematical laboratories, mainly at the pre-calculus high school level. The laboratories are to include a set of programmable pocket calculators (P.P.C.), one for each pair of students. The student should spend in these laboratories about a quarter of the time allocated for math studies. The construction of algorithms and their implementation in the laboratory will prevent the situation where a student "knows how to solve a problem but can't do it". A detailed plan along these lines, suitable for the pre-calculus as well as the calculus level, is set forth in our book "Computational Mathematics" which appeared in 1975.
>
> We suggest the use of "computing plans" which accompany the student throughout his studies. These computing plans are in the form of a sequence of language-independent instructions, tailor-made for any computer. They are readily keyed into a programmable pocket calculator, so that the student can "get his hands wet" and produce his own numerical results.

The idea was not to try to revolutionize the mathematical curriculum, but rather to modify it by putting emphasis on algorithms for solving meaningful problems and carrying them out to completion. This is to be

achieved by means of pocket calculators which are permanently located in the mathematical laboratories in which about a quarter of the time devoted to mathematics is spent. In such a laboratory, each pair of students work with one programmable calculator, as is the custom in working with the microscope in the biology lab.

Since it was our feeling that the promotion of such a program should start with the teachers, a mathematics laboratory was established in 1976 at the Levinsky Teachers College located in North-Tel-Aviv. Since 1976, these ideas have been developed and tried by Professors Brutman, Zwas, and Breuer with the future mathematics teachers at the College. In 1977, a parallel program was conducted by Ronit Hoffman at the Kubbutzim Teachers College, where she instructed future biology teachers. In both cases, the mathematics laboratory was equipped with 15 programmable SR-56 calculators, in addition to various other teaching aids. It has been decided to adopt the algebraic logic calculators over those with RPN, in order to conform with the students' prior learning experiences.

In general, the students accepted this new approach to mathematics studies with enthusiasm and with what can be described as "funfilled involvement". This was confirmed by attitude questionnaires examined during 1977. During these years, the first university theses on teaching mathematics with the help of calculators were accepted. The first of these was prepared by Ronit Hoffman at Tel-Aviv University on the subject, "Teaching Mathematics from an Algorithmic Point of View with the Use of Pocket Calculators".

At the Weizmann Institute of Science, Rachel Manber wrote a thesis on "The Development of a Unit Using the Hand Calculator in the Mathematics Curriculum for Junior High-Schools". This thesis was supervised by Professor M. Broockheimer and consists of three chapters intended to be inserted, at different stages, in the Rehovot-program for junior high schools.

At the Hebrew University in Jerusalem, Avigail Snir's thesis treats the use of calculators in teaching high-school algebra. Her work was supervised by Dr. Perla Nesher of the Department of Science Education.

Although detailed proposals were submitted to the Israeli educational authorities in 1975, 1976, and 1977, requesting support for an expanded program, regrettably (as of December 1979) none was forthcoming.

Concurrently with the above described programs, another Teachers College began introducing calculator-augmented mathematical studies into its curriculum. This was the Religious Teachers College at Bayit Vagan in Jerusalem. At this college, Dr. Amos Ehlich experimented with the use of calculators to promote the "learning of mathematics by discovery", and he reported very encouraging results. There was no doubt that the calculators -- the programmable models in particular -- added a whole new dimension to the students' ability to discover mathematical facts and to "do mathematics" rather than just hear and learn about it. Now and again, we were reminded of the saying that "Mathematics is like kissing; the only way to discover its delights is by doing it".

In 1977, the Israeli Open University in Ramat-Aviv developed a program for adult education in mathematics. A large part of this program was intended to be carried out via correspondence. Each student received, as part of his mathematics kit, an inexpensive non-programmable calculator as his own home-laboratory tool. This program was developed in cooperation with the Center of Educational Technology in Ramat-Aviv, which pioneered the introduction of computers and programming into the curriculum of Israeli high schools, under the directorship of Dr. Jona Peles. As a direct result, an optional matriculation examination on Computers and Programming has been offered since 1977.

Finally, it should be noted that programmable pocket calculators are rather expensive in Israel, and are therefore out of reach from the budgetary point of view of a single educational institution. Hopefully, this will change when the governmental and educational authorities come to the realization that a calculator laboratory, much like other science laboratories, should become a standard and vital part of every school.

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Calculators in Schools in Japan

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1. The Present Provision

a. Government policy

The Ministry of Education of the Japanese Government is encouraging school use of calculators in mathematics and science teaching by giving due attention to this matter in compiling the Course of Study and by giving financial support so that schools can be equipped with calculators.

b. Place in the curriculum

In both of the Courses of Study for the Elementary School (1st - 6th grades, 6-11 years old) and for the Lower Secondary School (7th - 9th grades, 12-14 years old), use of the calculator (in general) is encouraged as an aid for numerical computation in their sections of General Remarks, although it is not included in the Course of Study as one of the topics to be covered.

In the Course of Study for the Upper Secondary School (10th - 12th grades in full-time school and 10th - 13th grades in part-time school, 15-17 or 18 years old), use of calculators and computers is one of the topics to be covered in the subject Mathematics IIA of the present version of the Course of Study or Mathematics II of the revised version, to be enforced from 1982, both of which are intended to be studied by those students whose future careers are not scientific ones. In the mathematics subjects to be studied by students intending scientific careers, the concept of algorithm is included in the present version but omitted from the revised version. The use of calculators as an aid for numerical computation is again encouraged throughout all subjects in mathematics in the section of General Remarks as in those for the elementary and lower secondary schools.

c. Financial support by the government

From 1970 on, the Ministry of Education has subsidized half of the cost for schools to equip with calculators for classroom use, as part of a ten-year program of promoting school equipment for science and mathematics education, provided that another half will be covered by local money. The standard of such provision is as follows:

School and Type of calculator	Cost per unit	Quantity per middle-sized school
Elementary School calculator with 4 operations	¥10,000	6
Lower Secondary School calculator with memory and square root	¥35,000	10
Upper Secondary School I. programmable calculator with printer	A ¥320,000 B ¥235,000	7
II. computer or calculator with more functions	< ¥1,300,000	1

According to the survey carried out by the Ministry of Education in 1978, for the upper secondary school it seems that about 50% of the said standard level is fulfilled on the average throughout Japan.

d. Inservice training of teachers

In responding to the above provision, using and teaching calculators have been included, together with other topics, in the inservice training courses of one week or so organized by the training centers of prefectural boards of education and other organizations.

2. Instructional Practice

a. Example of Tokyo Metropolitan

According to the report prepared by the Calculator Study Group of the Association of Mathematics Teachers of Tokyo Metropolitan Upper Secondary School, among the 93 upper secondary schools who reponded to the questionaire sent from the Group, 71 schools are equipped with calculators. About half of them are using calculators in their mathematics classes and out-of-classroom activities, while the remaining half are not using calculators. Among the resons for not using calculators, the most popular ones are shortage of time and equipment.

b. Researches and experimental teaching

The Japan Association of Mathematical Education, a similar organization of mathematics teachers and researchers to the National Council of Teachers of Mathematics in the USA, publishes journals and convenes an annual meeting every year where teachers read papers on their teaching and exchange their experiences. In these journals and presentations in the annual meetings,

experiences of teachers who tried the teaching of calculators in and out of the classroom are reported. The following is a summary of these presentations.

For the elementary school level, several teachers reported their experiences of using calculators in their teaching of grade 5-6 students as being worthwhile, to be explored more deeply because it enabled students:

(1) to concentrate on an aspect of mathematical relation or principle in problems without being bothered and obscured by numerical complexity.

(2) to face with a meaningful situation where estimating results is essential.

(3) to feel enjoyment of manipulating a scientific tool.

For the lower secondary school level, no article or presentation is found in these literatures. The reason for this absence will be referred to in the later part of this paper.

For the upper secondary school level, how to use calculators in mathematics classes is one of the most popular themes presented in annual meetings. Among 100 and 97 papers read in the 1977 and 1978 Annual Meetings, 13 and 8 papers were on this theme, respectively.

Most of them are reports of trying out introducing calculators as an aid for teaching and learning traditional topics such as graphs of function, numerical solution of equations, differential coefficient, standard deviation, etc. Some of them are related to compiling and using the textbook or manual to be used for learning how to use calculators and flow diagrams. A few are related to its use in out-of-classroom activities such as "computer club and administrative business of teachers. They reported that students' reactions were positive for the use and teaching was successful, although sometimes shortage of time and equipment was strongly felt.

c. General trends

For the elementary schools, those teachers referred to in the previous section are to be regarded as exceptional cases. Generally speaking, it seems that many teachers are reluctant to introduce calculators in their classes, partially because of their belief that at the elementary school level teachers must concentrate on fundamentals and, before going into calculator work, students must master basic skills in computation without

special aids, and partially because of monetary problems involved and a fear of new change.

Among mathematics teachers of the secondary schools, one may find two different attitudes to mathematics teaching in relation to applications or the function of real situations. The one, which may be called "practice-oriented", is to emphasize a practical side of mathematics and to make the effort to include a certain aspect of model-making into their teaching as much as possible. Teachers of this attitude would welcome use of calculators in mathematics class as an indispensable aid. The other, which may be called "theory-oriented", is to emphasize basic understanding of mathematical concepts and to regard applications or real situations as only examples for illustrating those concepts concretely. In this attitude, numerical complexity in exercises is kept minimum even when a real-life problem is used as an exercise, so that students might be able to concentrate on mathematical aspects of problems without being bothered by the numerical complexity involved.

According to my observation, the majority of secondary school mathematics teachers seem to be on the side of "theory-oriented", and "practice-oriented" teachers are a minority. Especially at the lower secondary school level, where many new topics of algebra and geometry are introduced, teachers are likely to adopt the theory-oriented attitude. This may be a reason for the absence of papers and presentations on the theme of calculators at this school level.

In the upper secondary school level, preparation for university entrance examination is the most serious concern of general Janapese teachers. In the examination, it is not customary to allow the use of calculators, and many of the problem sets there are those of the theory-oriented. And so teachers who would like to put much emphasis on preparation tend to neglect use of calculators. Consequently, in academic courses, where students are preparing for examination, practical teaching of calculators is not so popular, while in non-academic courses it is becoming popular as a way of arousing students' interest in mathematics in spite of the fact that theory-oriented teachers may also be found there.

3. Future Prospect

Recently, the price of calculators has been falling year by year in company with much marketing effort on the side of the makers to the extent

that elementary school children can buy them with their pocket money and use them in their own ways in doing their homework. Perhaps the most urgent problem in this area is how to cope with this situation in the elementary school curriculum. Up to now, teachers and researchers have studied problems of how to facilitate school learning by the use of calculators while a main sequence and the weight of topics in the curriculum are kept as they are, but in the near future it will become inevitable to reconsider the said sequence and weight of topics by taking into account changes in educational needs and environment caused by the recent trends. It would be ineffective to cope with this situation only by prohibiting use of calculators in learning until children master fundamentals of computation. A more positive measure should be explored.

If we admit an assumption that calculators are always available in any classroom, then emphasis might be shifted from mastering a certain set of prescribed algorithms to developing various algorithms based on fundamental properties of number, and grading difficulty by number of digits in computation might become not so meaningful. These are a few examples of issues to be studied.

At present there is no such scientific and systematic research project on this issue, but I think such a project should and will be started in the near future.

Calculators in Schools in New Zealand

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Electronic hand-held calculators are widely available in New Zealand, although the prices, even to educational institutions, are probably not as low as they are in other countries.

Their use in schools tends to be on an informal basis. Only at Form 7 (17- to 18-year-olds) is the use of calculators recommended in official syllabuses. This is in the Applied Mathematics course, where it is suggested that calculators might be used to advantage in the Statistics and in the Numerical Analysis sections. The Department of Education provides up to nine calculators per school for this purpose.

The use of calculators is not permitted in national school-level examinations conducted by the Department of Education or the Universities Entrance Board, although some locally based regional examinations for low achievers in mathematics do incorporate their use. The National Consultative Committee on Mathematics has recommended that the use of calculators be allowed in examinations conducted by the Universities Entrance Board for senior high school pupils, but this is still under consideration. Problems have been raised concerning supervision, standardisation, etc., and above all, the difficulty of ensuring that all candidates, whatever their economic background, have equal opportunity of access to machines both for classwork and in examinations.

The National Consultative Committee also recommended that class sets of calculators be made available to every secondary school in New Zealand, but action has yet to be taken on this matter.

There has been little demand to introduce calculators in the School Certificate examination at Form 5 (15-year-olds) or at lower levels of the secondary schools.

The use of calculators in an individual school depends on the initiative of individual teachers within that school. There are many instances where classes have been equipped with calculators, often classes of low ability, and interesting approaches have been pursued. In most cases, though, calculators seem simply to be used to relieve the computational

burden of regular work, and seldom involve any qualitatively different approach.

Of the currently used locally written mathematics textbooks, only the most recent make any provision to incorporate the calculator. The most extensive treatment is found in a text designed for pupils of lower than average ability in secondary school.

Limited formal research has been conducted into the effects of using calculators. Two controlled trials have been made with classes at Form 2 and Form 3 having approximately 25-30 pupils in each. No significant difference in achievement was observed between those using calculators and those not.

A survey of a random sample of about one-fifth of the secondary schools in New Zealand in late 1977 asked teachers to estimate the percentage of pupils at various levels who had access to calculators. The results from 72 schools were as follows:

Number of Schools with Pupils Having Access to Electronic Calculators, by Class Level

Percentage of pupils with access to calculators	Level				
	Form 3	Form 4	Form 5	Form 6	Form 7
Under 10%	41	39	38	17	5
10 - 25%	12	13	12	18	5
26 - 50%	5	7	4	13	18
51 - 75%	4	3	6	6	11
Over 75%	0	0	1	7	15
Not stated, or impossible to say	10	10	11	11	18

It is probable that these figures underrepresent the true situation; many teachers recorded surprise at their findings when they checked their estimate with the class itself.

Little concern has been expressed by teachers, parents, or the community either for or against the use of calculators in New Zealand schools. There has been no strong pressure to introduce calculators into the curriculum, nor to exclude them. No in-service courses specifically directed to the role of calculators have been held, although general courses have usually included a session or two on the calculator. A national course

to establish guidelines for the use of calculators is to meet in mid-1980.

As evidence of this apparent indifference towards the calculator, articles from the New Zealand Mathematics Magazine are cited (see References). This is the principal professional journal for secondary school mathematics teachers in this country, and each issue is usually about 30 pages in length. This particular issue (May 1978) was to be devoted to the classroom use of electronic calculators, but little material was forthcoming. Other issues have included occasional articles on calculators, or games and enrichment activities for pupils with calculators.

As has often been true with developments in mathematics education in New Zealand in the past, the experience of other countries is being observed carefully. It is probable that a projected revision of the Form 1 to 4 mathematics syllabus in the near future will incorporate the calculator, probably as a teaching aid. In the meantime other issues in mathematics education in this country appear to be of greater priority.

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Calculators in Schools in Sweden

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The use of hand-held calculators in Sweden is, of course, a novelty of the past few years. The first directives from the Board of Education (S Ö) came in 1975, and this year some trials started both in the gymnasium (grades 10-12) and in the upper forms of the compulsory school (grades 7-9). In March 1976, a committee called the ARK-group was set up. ARK stands for "Analysis of the Consequences of Calculators", and the group is primarily responsible for finding problems and initiating researches. I will refer to a summary given by the chairman of the group, Hans Brolin, and account for problems and for projects which are going on or are planned in the near future.

Use of calculators in schools can be looked upon in three different ways:

1. As an aid for calculation.

This means that calculators replace slide rules and tables. No problems have been formulated for grades 10-12, but for grades 7-9 we must propose demands upon skill by calculation with fractions and decimal numbers. If calculators will be used in grades 4-6, paper-and-pencil computation by algorithms may be reduced. What influence can this have on the pupils' (a) concept of number, (b) estimate of calculation, (c) ability to choose the right operation, and (d) skill in calculation? Which aims shall be stated for the algorithmic skill?

2. As an aid in order to change methods in the present curriculum.

In all the actual stages there are the following problems:

(a) Is the calculator an aid in introducing certain concepts?

(b) Can the calculator develop pupils' capacity and inclination to solve problems?

(c) Can the courses of today be more applied and oriented on problems?

(d) Can laboratory work with calculators be introduced?

For grades 10-12, other questions at issue are fomulated:

(e) Can programmable calculators change the methods in teaching mathematics?

(f) Can they influence the pupils' interest and motivation for mathematics?

3. As an aid in order to change the contents in the present curriculum.

At all stages we need new ideas, their examination, and the elaboration of proposals. For grades 10-12, we also must think about programmable calculators. In connection with those problems, the ARK-group has initiated some projects.

Projects which are going on

1. For all stages: Mapping of the international development and research work about introducing calculators in schools. A first report was published in September 1979.
2. For grades 4-6: The RIMM-project, which deals with curriculum, methods, and demand on arithmetic skills. With the help of an earlier project, PUMP (Processanalyses of Education in Mathematics/Psycholinguistics), RIMM has analyzed the arithmetic for this stage. They recommend more table knowledge, mental calculation, and estimation than now, but some decrease of calculations with algorithms. There will also be more verbal problems and laboratory work. Material for grade 4 is being tested as an introduction in some classes this year. An extensive description of the project appeared in December 1979.
3. For grades 4-9: Non-manipulative mathematical skills. That means conception of the size of numbers, ability to choose the right operation by calculation, interpretation of diagrams, and so on. The purpose is to describe and define such skills and to make tests in order to measure them continuously. Skills of this type may perhaps replace the decreasing algorithmic drill. Tests were given in grades 6 and 8 last year. Results have been statistically analyzed and were partly published in December 1979. A description of the goals is in a preliminary version and will lead to a proposal of new methods, which will be published soon.
4. For grades 7-9: Laboratory work with calculators for pupils with a lower score. Subjects for the work come from discussions with the pupils and the work will dispose of about one-fourth of the time available for mathematics.
5. For grades 10-12: Methodics in the NT-streams (with an emphasis on mathematics and science). An extensive compendium with methodological experiences and advice or suggestions is prepared and hopefully already

used in many schools. Materials for the SE-streams (with an emphasis on civics and economy) will be published soon.

6. For grades 10-12: Programmable calculators for teaching probability. The textbook "Sannolikhetslära och simulering" (Probability and Simulation) has been tested in some classes for the last two years. The author, Lennart Råde, is inspired by the "algorithmic thinking" of Arthur Engel. Teachers are invited to use the text next year and to give their opinions about it.
7. For grades 10-12: The NUMA-project, which deals with numerical methods in mathematics and physics. Programmable calculators or minidators (BASIC) are used. A number of textbooks have been produced. A preliminary enquiry has been published.

The planned new projects are mostly extensions to other stages or streams. More information can be obtained from:

Hans Brolin, Uppsala Universitet, Institutionen Lärarhögskolan, 751 05 Uppsala

or from the leader of project 1 (international development . . .):

Karl Greger, Göteborgs Universitet, Institutionen Lärarhögskolan, 431 20 Mölndal.

Calculators are now generally used in the grades 10-12 directed towards mathematics and science, and often used also in other classes of that stage. I think that they are used most frequently for calculation and as a table, and still are not used often as a methodical aid. Calculators are now allowed as aids in examinations, including programmable types. Also, in grades 7-9, many pupils have calculators of their own. However, they are not allowed at the central examinations in grade 9. Many teachers and parents are skeptical about the use of calculators in this stage. Perhaps experiences and results from different projects will set their doubts to rest.

In summary, I think that the knowledge and experience with calculators and their use in schools is relatively advanced in Sweden compared with many other countries. This is especially true in terms of the preparation for changing of the curriculum (NUMA and other projects). That will also lead to alterations in other subjects (physics, civics), where numerical and finite methods can be used extensively.

Calculators in Schools in Switzerland

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1. Introduction

This brief report about calculator use in Swiss schools first gives a survey of the Swiss educational system, then sketches the general situation of the reforms concerning the teaching of mathematics, presents trends and decrees of calculator use in cantons as far as known, and also treats the relation between pocket calculators and the teaching of informatics.

2. Educational system of Switzerland

Any description of educational trends in Switzerland for the foreign reader has to begin with a short description of the organization of the educational system.

The 26 cantons and half cantons of the Swiss Confederation have a large measure of autonomy in educational matters (since 1848). As a result, there is no national Ministry of Education in Switzerland but 26 cantonal ones, due to the diversity of cultures, characteristics, and languages of Switzerland's regions. Therefore, the "Swiss educational system" is very complex and decentralized; responsibilities are broadly distributed on the Confederation and the cantons.

a. Confederation responsibilities

- maintenance of the polytechnical colleges (Zurich, Lausanne)
- contribution to the cantons' costs by awarding study grants
- promotion of scientific research
- legislation in the vocational field
- regulations as to the recognition of certificates giving access to higher education (e.g., universities)

b. Cantonal responsibilities

- organization, management, and supervision of elementary education; each canton has a School Act which defines the respective responsibilities of the cantonal and local authorities for the several educational levels (kindergarten, primary, lower secondary education)
- School coordination in order to harmonize cantonal school systems; a concordat on school coordination of the Swiss Conference of Directors of Education (SCDE) which tries to harmonize beginning

of school year, duration of schooling, type of school, educational objectives, and curricula. This school coordination is based on recommendations which are not binding; progress is therefore very slow and unsatisfactory in many respects.

As to the teaching of mathematics, a Committee of Mathematics Instruction of the SCDE organizes every year a conference (Forum für Mathematikunterricht) where experts and teachers exchange their opinions about topics like: the role of the function, mathematizing activity, objectives in geometry, use of calculators, etc.

There are also some common responsibilities of Confederation and cantons which are not further described here.*

3. Mathematics instruction in Switzerland

The problems arising from the cheaply available calculators for mathematics instruction must be seen on the background of trends and practices in the teaching of mathematics and on the one of the Swiss educational system. The responsibility for mathematics instruction on the primary and the lower secondary level belongs to the cantons. Therefore, only a rough picture of its situation can be given. Compared to other European countries, reforms in mathematics instruction began late in Switzerland. Some cantons are just now starting to plan innovations in mathematics instruction. Further, the changes in teaching objectives were rather moderate and perhaps reforms were rather concerned with teaching methods than with "new math". Innovations in this field are characterized by the well-known "Swiss pragmatism".

The evaluation of recent innovations in mathematics teaching must be judged insufficient with a few exceptions, mainly in the French-speaking part of Switzerland. This statement is important because the weak infrastructure for educational research in Switzerland generally, and a lack of continuity in didactical research especially, do not give rise to hope that problems related to the introduction of calculators can be easily solved and scientifically mastered.

Two other facts confirm this situation:

- The concepts and objectives of mathematics curricula are oriented rather formally and not towards real-life and everyday mathematical problems.

* For further details see Egger and Blanc (1974).

- The coordinating possibilities of the Committee of Mathematics Instruction of the SCDE are probably too limited to promote the necessary cooperation in research, development, and evaluation related to calculator use in schools.

On the other hand, this situation of disunion also gives room to a multitude of ideas, strategies, developments, experimentations, and mutual cooperation in and between the several cantons or regions. At present, curriculum guidelines in the form of fixpoints at which objectives must be attained in all cantons are developed by the Committee of Mathematics Instruction of the SCDE. These guidelines are not yet definitively formulated. They contain, among other guidelines, the following ones:

- Students must learn to reasonably use aids as e.g., graphs, tables, calculators, etc.
- Calculators can be used for the training for arithmetic skills.

The fact that calculators are mentaioned among other aids seems to be significant for how calculators in the classroom are seen for the time being in Switzerland.

4. State of the art of calculator use in elementary education

We are not able to give a precise picture of calculator use in mathematics instruction on the elementary level (comprising primary and lower secondary level or grades 1-9). Of course, there is a calculator in almost every household, causing a more or less uncontrolled introduction of the calculator in school in grades 6-9 without clear ideas on how to use them (e.g., as a teaching aid to enable better learning of concepts or only as a calculating aid). That is why the Committee of Mathematics Instruction of the SCDE held a conference in 1977 to discuss the corresponding problems (Mathematikforum III, 1978). The conference passed five recommendations which were influenced in some respect by preceding ones of the mathematics teachers of the upper secondary level. The recommendations were:

1. It is desirable to make use of calculators in mathematics instruction not later than after grade 7.
2. Changes in curricula are for the time being not necessary because of the use of calculators.
3. Calculators ought to be used to enable pupils to come to a better understanding of concepts.
4. Teaching aids and materials and training should be offered to teachers.

5. It is important to carry out and coordinate experiments which enable giving answers to the problems related to the use of calculators.

An inquiry by questionnaire with all cantons shows that these recommendations are as yet not followed thoroughly, though this statement may be premature. Although this inquiry, made in 1977 and completed in 1979, cannot give a precise picture of the use of calculators in school, some conclusions can nevertheless be drawn:

(a) Form and liability of the several cantonal regulations differ vastly. They reach from official and detailed regulations to informal recommendations. Thirteen cantons (of 26) have issued a binding decree and 13 cantons have no definite regulation but rather a provisional recommendation; five cantons of these 13 gave no information about trends or practice of calculator use.

(b) If one looks at the cantonal regulations and recommendations by level we get the following situation:

- Primary level (School years 1-5 ca.)
  Twelve cantons reject the use of calculators and eight cantons give neither a regulation nor a recommendation. Only one canton (Geneva) encourages teachers to use calculators regularly. We conclude that on the whole the positive possibilities of using calculators in the primary grades are not yet recognized or accepted and therefore distinctly rejected.
- Lower secondary level (School years 6-9 ca.)
  Fourteen cantons officially or unofficially allow calculator use in a more or less restrictive sense; that means that, e.g., only during the last two or three obligatory school years (grades 7-9) are calculators allowed (though generally not on tests). Six cantons ban calculators for quite different reasons: either because of a general objection or because of the necessity of further investigations of related problems. Two cantons give neither a regulation nor a recommendation. In contrast to the primary level, we conclude that on the lower secondary level we encounter a more liberal attitude toward calculator use.
- Upper secondary level (School years 10-12 ca.)
  The inquiry did not explicitly concern this post-obligatory level. The fact that no objections were made in the cantonal

answers and that 12 cantons do not even mention this level allows the conclusion that calculators (pocket and desk calculators or, in the case of informatics, terminals connected to computers) are almost fully integrated in the teaching of mathematics. In vocational education we could state the same, as far as we have information.

As to innovational strategies, we observe the following ones: due to Recommendation 2 of the Mathematikforum III, curricula remain unchanged for the time being. Additional teaching aids (calculator supplements) to existing curricula have been or are going to be developed (by every canton itself or by some cantons cooperatively). Teacher training is provided in some cantons to instruct teachers how to work with calculators during lessons, with the aim of assisting the existing curricula. We have no information of curricula under development which could be considered as calculator-modulated or even calculator-based curricula (as proposed by Weaver, in Suydam, 1976, p. 229).

5. Calculators and informatics instruction

The availability of cheap programmable pocket calculators raises the question of their use in informatics instruction. In Switzerland informatics is taught almost only on the upper secondary level, though in a few cantons it is offered also on the lower secondary level as an option.

Informatics as a teaching subject is accepted for its pedagogical value. A group of experts states in a report written for the SCDE that an introductory course in informatics (on the upper secondary level) of at least 24 obligatory hours suffices to enable the pupils

- to use this introductory knowledge in different disciplines during the rest of his studies
- to pursue the study of informatics as an option.

The introductory course should be held not later than during the tenth school year (for more details see: "Die Einführung der Informatik an den Mittelschulen", 1978).

In this report, a slight discoordination in aims and contents of several ongoing courses is mentioned. It seems, however, that the fundamental objectives of informatics instruction are not seen too differently by the cantons. The report gives no concrete indication on the use of the programmable pocket calculator, but rather on that of desk calculators

and computer terminals, the objective being to reach knowledge of a "higher programming language". Though we know that in some schools programmable pocket calculators are used for an introduction to informatics, this seems to be an interim solution which will be modified in favour of desk calculators with, e.g., BASIC and FORTRAN languages.

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Calculators in Schools in Thailand

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So far, the issue regarding the use of calculators in schools has not been seriously considered among Thai educators, in-as-much as calculators are less available in Thailand than in some other countries. Research activities on their use and effects on student outcomes do not exist. However, it is of interest to explore what teachers and instructors think about the role of calculators in the classrooms. This paper reports the results of a survey.

A questionnaire was sent to different strata of mathematics teachers and instructors to obtain answers to the following questions:

1. Are calculators used in schools?
2. How should calculators be used in schools?
3. At what levels should calculators be used in schools?
4. What is the role of calculators in teaching mathematics?
5. Should calculators be used in testing situations?
6. Should a student have a calculator?

The sample consisted of 5 mathematics teachers in primary schools, 77 mathematics teachers in lower secondary schools, 41 mathematics teachers in upper secondary schools, 12 mathematics teachers in vocational schools, and 12 university mathematics lecturers. These persons were selected from teachers in Bangkok and rural provinces.

The analysis of data from the survey

In primary schools, four out of five teachers reported no calculators in schools; only one teacher reported the existence of calculators. They reported that approximately 5 percent of their students used calculators belonging to their parents to compute the answers to homework problems. Most of the teachers felt that calculators should not be used in classroom teaching or in testing situations; they suggested that calculators should be used in vocational schools and universities, however. It should be a duty of the students, not the schools, to purchase calculators.

In the lower secondary level, 58 of 77 teachers reported the use of calculators in the schools, but for business and administrative purposes rather than as a teaching aid. The rest of the teachers reported that no calculators were used. The teachers reported that 20 percent of the students used calculators to compute the answers to mathematics problems. These figures indicate that calculators are used in lower secondary schools more than in primary schools. Most of the lower secondary school teachers felt the calculators should not be used in teaching mathematics or in testing situations; they suggested that calculators should be used at the vocational school and university levels. The perceptions of this group of teachers is similar to that of the primary school teachers.

In the upper secondary school level, most of the teachers reported the existence of calculators in schools. These calculators were used for business and administrative purposes rather than as a teaching aid. The teachers indicated that approximately 20 percent of their students used calculators. Most teachers thought that calculators should not be used in teaching mathematics or in testing situations. They suggested that students in upper secondary level should use calculators, but only for computing the answers to complicated problems. The perception of this group of teachers is quite different from that of primary and lower secondary school teachers. Most of the teachers felt that the students should purchase the calculators themselves.

In vocational schools, 10 of 12 teachers reported that calculators in their schools were used for business and administrative purposes rather than as a teaching aid. They indicated that approximately 65 percent of the students used calculators in the classroom for computing answers to problems. The figure showing the use of calculators in vocational schools is greater than that in primary and secondary levels.

At the university level, 8 of 12 mathematics instructors reported the use of calculators. They indicated that approximately 10 percent of their students used calculators to compute the answers to complicated problems. The majority of the instructors felt that the calculators should be used in teaching and in testing situations, and that the universities should provide the calculators. They believed that calculators should be used at both vocational school and university levels.

The results of the survey as reported indicate lesser acceptance of the use of calculators in primary and secondary schools than in the vocational schools and universities.

The reasons for using calculators in schools

1. Calculators reduce instructional time; therefore, teachers can devote more time to teaching concepts and content.
2. Calculators aid in computing answers to problems and hence motivate students to solve mathematics problems.
3. Calculators lessen computing errors.
4. Since the role of calculators in society is increasing, the students should learn how to use them.
5. Calculators enable the teachers to include on tests more items which measure mathematical concepts and reasoning.

The reasons for not using calculators in schools

1. Calculators are not available to all students.
2. Calculators decrease the students' ability to calculate.
3. Calculators are not appropriate for use in the primary level because students are working with small numbers.
4. Calculators lessen the students' ability to think.
5. Calculators lessen the students' ability to memorize.
6. The students will not understand the computation algorithms if they use calculators.
7. Calculators do not motivate the students to learn mathematical principles or think through mathematics problems. Moreover, they lessen the students' understanding of mathematical structures.

The above discussion provides some useful information concerning the use of calculators in Thai schools. The survey was limited to the small sample used. However, the results of the survey reflect that Thai teachers have concerns about the use of calculators by their students. Since calculators are having more impact on daily life, educators and curriculum planners should start considering the effect of calculators on teaching and learning mathematics. This suggests that more research activities should be conducted in Thailand to investigate the possibility of using calculators in schools.

Calculators in Schools in the United Kingdom

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Calculators seemed to be in some U.K. schools by 1973, and the first reports of any activity were included in a general review (Fielker, 1973) which considered the educational implications, comparing the possibilities of the calculator with other historical aids to calculation, and looked at the types of machine then available.

Many individual schools were buying machines and using them in various ways. The initial attraction was the same relief from tedious calculation that caused some secondary schools to welcome the slide rule some ten years earlier, especially those partaking in the School Mathematics Project. However, the calculator seemed to shake more than ever the traditions of arithmetic, and when S.M.P. canvassed its schools in 1977 to see if they wished calculators to be permitted in public examinations, there was sufficient support either way to warrant the establishment of two examinations, one in which calculators were forbidden and one in which they were permitted.

Experimentation was largely exploratory and informal. The Inner London Education Authority, for instance, provided money for 200 four-function machines which were allocated to one secondary and four primary schools in 1975. An informal interim report (Fielker, 1976) indicated that there was some reluctance on the part of the teachers in primary schools and the mathematics teachers in secondary schools to use the machines, although they were welcomed by teachers of science, geography, technology -- an indication that the main purpose in mind was computation. However, the reporter's own anecdotal accounts of work with children indicated possibilities for creating situations in which children's understanding or misunderstanding of number was thrown into relief, and the report contained many suggestions as to how calculators could be used, not only to perform any necessary calculation, but to cope with the realistic numbers thrown up by practical problems, to deal with more complicated numbers when meeting new mathematical ideas, and to do some new pieces of mathematics that would be inappropriate without a machine, including the development of machine algorithms as opposed to paper-and-pencil algorithms.

The School Mathematics Project (1977) reported on its own investigation conducted in seven of its schools in 1976-77. It reflected various levels of enthusiasm, and confirmed feelings elsewhere about the possibilities for calculators, including the motivation of less able pupils, and hints that all pupils could become more numerate rather than less.

Durham Education Committee (1976) reported more enthusiasm in four secondary schools who used calculators in 1973-76, and the report contains useful practical suggestions about organisation as well as ideas for mathematical activities. A subsequent experiment with 16- to 18-year-old students (Neill, 1978) revealed a wealth of ways in which calculators could be used as an aid to teaching and understanding many of the topics normally studied in the sixth form, particularly in the areas of analysis and numerical methods.

In 1977 the Shell Centre for Mathematical Education at Nottingham University set up a Schools Calculators Experimental Working Party, to which they invited anyone known to be organising experimentation, which, as well as representatives of the bodies already mentioned, included members of the Association of Teachers of Mathematics involved in a primary school experiment, and people from the Birmingham Structured Mathematics Scheme who were writing material for primary children.

The Shell Centre had itself set up an experiment in a primary school, and the report on this (Bell et al., 1978) gives considerable detail about areas of use, advantages and disadvantages, children's reactions, and implications for the curriculum. It is very optimistic, and supports findings from elsewhere that calculators improve numeracy rather than otherwise. It identifies more or less the same modes of use as the I.L.E.A. report (Fielker, 1976) and also suggests some useful games.

Advice to schools about hardware has been given in various ways. In general, local authority advice has been given about which makes and types of machines are thought suitable, and nationally some advice has been given about general principles, as much to try to influence manufacturers as to tell schools what to consider (Jesson and Kurley, 1975; New, 1977; ATM, 1977; CET, 1978). Advice about software has been incorporated in the usual inservice training programmes, mainly at local teachers' centres, or automatically formed part of experiments like those described above. Individual activities have sometimes been reported in journals (Coward, 1978; Russell, 1977).

The effect on public examinations has been reasonably rapid. By 1978, half of the eight boards administering the General Certificate of Education in England were permitting the use of calculators at Ordinary Level, and two of the others were permitting them at A-level, while the Scottish Board was permitting them in all examinations. Regional boards for the Certificate of Secondary Education have been slower to change; only two out of fourteen boards were permitting them in their mode i examinations in 1978, but most of the rest allowed them in mode iii examinations (conducted by schools and moderated by the board). Where calculators are allowed, their use is sometimes forbidden for certain questions or in certain papers. Some comments on this are in Fielker (1979).

Attitudes towards calculators have varied enormously, as typified by the statement in Bell et al. (1978):

> . . . the attitude of primary school staff to the calculator ranges from an enthusiastic welcome through passive tolerance to hostility.

Secondary schools, as always, are influenced most by public examinations, and while they have a choice of boards for G.C.E., the restrictions of C.S.E. in most regions have not encouraged schools to use calculators with average and below-average pupils. Furthermore, some employers have been vociferous in their demands for arithmetic without calculators. It is sometimes difficult to persuade teachers that calculators are not detrimental to arithmetical health, in spite of continuing evidence in the U.K. and from abroad that the use of calculators improves ability at computation.

Primary school teachers, influenced by secondary schools, and perhaps loth to see their main mathematical activity suddenly replaced by machine, are even more shy of change. While some are willing to look into the possibilities, the majority are worried that arithmetical skills will be forgotten. Said one teacher, "I think they should only have calculators after they can do the arithmetic." The illogicality here is the same as that exhibited by the examinations in which arithmetical questions must be done without the calculator!

Even among the more enthusiastic schools, the calculator has been assimilated into existing curricula, and no one so far has altered the curriculum to take account of the calculator. However, there is enough development taking place to indicate the way things eventually should go.

Girling (1977), for instance, has defined basic numeracy as "the ability to use a four-function electronic calculator sensibly", and here and elsewhere (Girling, 1978) he attacks the place held by the algorithm:

> . . . paper and pencil algorithms . . . should only be taught as part of the armoury of techniques that we have to help in understanding of number and not because they are useful. (Girling, 1977)

Johnson (1978) takes the idea further.

> Pupils need to be given the opportunity to design their own algorithms or to modify existing procedures to do new tasks.

As an example of this, Fielker (1976) relates how some ten-year-olds composed their own algorithm for finding a square root, one that was probably more satisfactory on a calculator than standard iterative procedures.

Certainly all evidence so far indicates that when calculators are used, motivation increases and understanding of arithmetic is enhanced. Fielker (1972, 1976) also gives instances of how misunderstanding is revealed, sometimes after apparent success with paper-and-pencil methods. Furthermore, evidence suggests that even pencil-and-paper methods do not suffer from the use of calculators.

However, one questions whether this last point is valid, and whether written arithmetic is any longer necessary. Girling, Johnson, and others suggest not. What is required is an ability to check that answers are reasonable; hence a facility with "single digit" arithmetic, and a sense of the size of numbers to be expected in real situations.

In fact, the solution of arithmetical problems can be thought of in three stages:

(1) the various processes that must take place in order that information and instructions can be entered into the calculator;

(ii) the calculation;

(iii) interpretation of the answer.

In practice, particularly with younger children, the bulk of time in the classroom is devoted to the middle stage, and most of that time children are learning or practising arithmetic rather than using it to solve any problems at all. When the calculator replaces the middle stage completely, perhaps more attention can be paid to the other two, and children can learn more about solving problems.

But this is only one aspect of the calculator, as a replacement for calculation. It should also be considered in the general category of aids to learning, in company with rods, blocks, or other structured materials, so that as well as using it to do arithmetic, teachers can ask how it can help an understanding of mathematics, and what interesting problems it can present. The literature already abounds with suggestions.

Lastly, it is worth pointing out that, if nothing else, calculators are with us. It is interesting that one of the first boards to allow calculators to be used at G.C.E. O-level was virtually forced into doing so, because the previous year many candidates had used them anyway, there being no regulations to the contrary! Straw polls reveal that more and more pupils in school have their own calculators, or at least have access to one at home. They are used in most places of employment where calculation is necessary, and by customers in supermarkets. Unless we effect the necessary changes in educational attitudes, it could be that the classroom will be the only place where arithmetic is done by hand!

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Calculators in Schools in the United States

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Educators in the United States began to give serious attention to the use of calculators in schools by early 1975, just as (although not solely because) the prices were beginning to plummet. The National Science Foundation, concerned about the potential impact of the calculator, funded an investigation involving a critical analysis of the role of the calculator (Suydam, 1976). In June 1976, the National Institute of Education and the National Science Foundation sponsored a Conference on Needed Research and Development on Hand-Held Calculators in School Mathematics, in which participants were charged to "produce a planning document that will provide a well-defined framework for future research and development efforts." This was followed up by a second conference in January 1979. Meanwhile, in March 1977, NIE funded the Calculator Information Center, to collect and disseminate information about calculators to teachers and others interested in their use in schools; this supplements the services offered since at least 1974 by the National Council of Teachers of Mathematics. The federal agencies and the NCTM have not been alone in their concern about providing direction and materials. The Center was to serve as a clearinghouse for knowledge about the numerous activities and publications being developed around the country.

While not every household in the U.S. has a calculator, marketing figures indicate that over 80 million calculators have been sold since 1978. Increasingly, these data have reflected sales not only to individual parents, who may let their children use the tool, but also sales to schools. Not surprisingly, the calculator was readily accepted at the college level; at the secondary school level, there has also been a high degree of acceptance (although not by all). The calculator was recognized as a tool which could help to save time spent on hand calculation and thus allow more time to be spent on mathematical ideas and on more interesting content and problems.

From the junior high school downward, hesitancy about using calculators increases. In the elementary school, use of calculators is greater at the intermediate level (grades 4-6) than at the primary level. The most obvious reason for this is the widespread belief, held by both parents and teachers, that children should master the basic facts and algorithms before they use

calculators. There is some indication that the tendency to use calculators may be associated with the teacher's mathematical background: the greater the teacher's knowledge and confidence about mathematics, the more secure he or she may feel with a tool that can process numbers so quickly. The "back-to-the-basics" bandwagon has also undoubtedly played a part in suppressing use of calculators at the elementary school level.

Reasons For and Against Using Calculators

In the survey conducted for the NSF (Suydam, 1976), reasons cited by educators and in articles for using or not using calculators in schools were compiled. Literature published since then has affirmed the continuing acceptance of these reasons for using calculators:

(1) They aid in computation.

(2) They facilitate understanding and concept development.

(3) They lessen the need for memorization.

(4) They help in problem solving.

(5) They motivate.

(6) They aid in exploring, understanding, and learning algorithmic processes.

(7) They encourage discovery, exploration, and creativity.

(8) They exist. This pragmatic fact is perhaps the most compelling.

The reasons for not using calculators also continue to have pertinence:

(1) They could be used as substitutes for developing computational skills.

(2) They are not available to all students.

(3) They may given the false impression that mathematics involves only computation and is largely mechanical.

(4) There is insufficient (long-term) research on their effects.

(5) They lead to maintenance and security problems.

The first concern is one expressed most frequently by parents and other members of the public. But few educators believe that children should use calculators in place of learning basic computational skills. The data from PRISM, the survey of Priorities in School Mathematics, confirms this point. But there is a strong belief that calculators can help children to develop and learn more mathematical skills and ideas than is possible without the use of calculators.

Teachers' opinions about calculators are slowly changing. However, they are much more likely to be positive if they have local leadership which is aiding them to see the role of calculators in their classrooms.

Extent and Type of Use in Schools

One of the most frequently asked questions is, "How many students are using calculators in schools?" One survey, conducted with over 22,000 students in the Shawnee Mission (Kansas) Public Schools indicated that, in 1977, between 20% and 40% of their students owned calculators, while 65% to 80% of them had access to calculators (Parks, 1977). Substantial increases were found at each of three school levels between 1975 and 1977, with percentages of ownership increasing with level.

The results of two national surveys provide additional information. During Winter 1977, Weiss (1978) queried a random sample of 1177 schools representative of the total U.S. school population. They indicated increasing use as grade level increased:

	Grade Level			
	K-3	4-6	7-9	10-12
Schools having calculators	28%	36%	49%	77%
Teaching using calculators in science classes	2%	12%	10%	36%
Teachers using calculators in mathematics classes	6%	14%	30%	48%
Teachers indicating calculators not needed	77%	44%	42%	33%
Teachers indicating calculators needed but not available	15%	39%	28%	18%

Data from the Second National Assessment of Educational Progress in mathematics (conducted in 1977-78) indicate that over 75% of the 9-year-olds, 80% of the 13-year-olds, and 85% of the 17-year-olds queried had access to at least one calculator (Reys, 1979).

When teachers encourage the use of calculators in instruction, children are likely to acquire them to use both in and out of school. In several school districts, competency with calculators is included on the list of minimal competencies expected for graduation. As state departments of education prepare new guidelines for the schools in their states, some mention of the role of calculators is generally included. The NCTM "encourages the use of calculators in the classroom as instructional aids and computational tools".

Just as data on the extent of the use of calculators are limited, so are data on the types of uses being made of calculators. In general, however, four uses predominate when teachers discuss how they use calculators:

checking computational work done with paper and pencil; playing games which may or may not have much to do with furthering the mathematical content, but do provide motivation; calculating whenever numbers must be operated with; and exploring mathematical ideas. Graeber et al. (1977) conducted a survey in 1977 of over 1300 teachers in grades 1, 3, 5, and 7 in three eastern states. These teachers cited, in addition to checking, the use of calculators for drill, motivation, remediation, and problem solving. Between 15% and 20% of the teachers indicated that they were using "instructional materials specifically designed for use with the calculator", although the nature of those materials was not noted.

Research on Calculator Effects

Over 100 studies on the effects of calculator use have been conducted during the past four or five years. This is more investigations than on almost any other topic or tool or technique for mathematics instruction in the U.S. during this century, and calls attention to the intensive interest about this potentially valuable tool. Many of these studies had one goal: to ascertain whether or not the use of calculators would harm students' mathematical achievement. The answer continues to be "No". The calculator does not appear to affect achievement adversely. In all but a few instances, achievement scores are as high or higher when calculators are used for mathematics instruction (but not used on tests) than when they are not used for instruction. Unfortunately, many of the reports have not carefully documented just how the calculator was used, so that specific ways in which the tool might have enhanced mathematical learning are unknown.

In the second NAEP assessment, approximately 25 exercises were assessed at each level, with many of the same exercises presented in a paper-and-pencil format as well. On exercises with routine computation (for which algorithms had been taught), performance was better when calculators were used than when paper and pencil were used. On exercises with non-routine computation, performance was poor, with no advantage from using calculators. On concepts and understanding, performance was also very poor, and the calculator had no positive effect. Performance on applications and problem solving varied, but it was clear that "calculators do not solve problems, people do" (Reys, 1979).

There have also been some studies which indicate that children learn basic facts and skills with the use of calculators, and they learn mathematical ideas (such as understanding of mathematical properties). There is also

evidence that children do not tend to use the calculator when they realize that it is unnecessary. In general, we know that calculators can facilitate instruction, making certain approaches to content more feasible than otherwise would have been the case.

Recently, several researchers have been exploring the role of the calculator in relation to problem solving. They have attempted to document how students go about solving problems when calculators are available. It is evident that there is a need for many more studies to provide knowledge of how calculators can be used to facilitate learning across mathematical topics and levels.

Development of Instructional Materials

Teachers who want to use calculators find that they need specific materials if they are to integrate calculators into instruction. Textbook companies have generally been wary; several have published supplementary materials, but few do more than mention in their regular texts that calculators might be used. Therefore, individuals and groups have developed materials to provide motivational activities and to make use of the unique capabilities of the calculator. Monies from federal agencies have been devoted to some of these efforts, although at a relatively low support level. In one such program, Rising et al. (1978) are developing instructional materials for grades 11 and 12. Immerzeel, who for some years has been exploring the problem-solving strategies which children use, has developed workbooks and sets of problems which incorporate the use of calculators to teach specific problem-solving strategies (Duea et al., 1978).

In a number of school districts around the country, the development of materials is also proceeding. For example, the Columbus (Ohio) Public Schools have prepared supplementary modules for grades 4-6. A group of teachers in the Minneapolis (Minnesota) Public Schools produced a set of worksheets on number concepts and consumer applications for grades 9 and 10. Several of the state mathematics councils have similarly involved members in developing materials.

Other groups have focused on meeting the needs of teachers for in-service experiences with calculators. The North Carolina Department of Public Instruction has developed a kit of materials to aid in conducting workshops for teachers. At meetings of such organizations as the NCTM and the School Science and Mathematics Association, workshops are included on the

program. Of even more interest are the numerous school districts across the country which have initiated workshops for teachers (and, in some cases, parents).

An increasing number of books and articles in educational journals present ideas for integrating the calculator into the on-going instructional program. The needs of specific groups of students are also being considered. A group of educational agencies, for example, has worked together to develop materials to help visually handicapped persons use calculators.

Continuing Concerns

The majority of the materials which have been published contain activities for incorporating calculator use in the existing curricula. Some of the recommendations of the Conference on Needed Research and Development on Hand-Held Calculators in School Mathematics concerned curriculum development for the long-range future. The 1979 NIE-sponsored conference specified in more detail the points made at the first conference, as well as exploring additional needs. The participants strongly suggested that a reiteration of the concerns expressed at the first conference is vital. While the conference report has not yet been developed, it appears that, among other points, it will stress the need for:

- Research on how calculators can develop mathematical skills and concepts at all levels.
- Development of instructional materials which integrate the use of calculators.
- Continuing evaluation of the effects of calculators on achievement and attitudes.
- Continuing concern for the needs of all types of learners as they use calculators.
- Emphasis on providing preservice and in-service teachers with calculator experiences.

Another continuing concern is with the role of calculators on tests. There is a stalemate at present: it is not appropriate to use calculators on normed tests; on the other hand, tests which allow the use of calculators will not be available until calculators are in much wider use. Teachers, however, have become aware of the need to develop classroom tests which assess mathematical ideas, rather than computational accuracy, when students use calculators.

Concluding Comment

Slowly, but surely, the calculator is being incorporated into the program at all levels in U.S. schools. It is being recognized as an instructional tool which has certain capabilities. Continuing research to explore its potential for aiding mathematical learning and continuing curriculum development to provide materials to help teachers realize its potential are both vital components of the process.

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Calculators in Schools in West Germany

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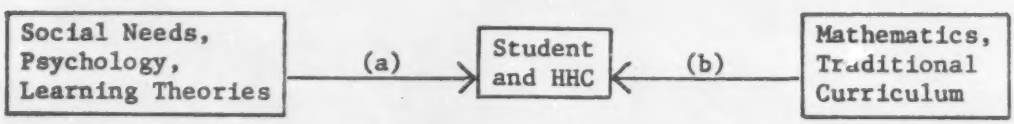
1. Dissemination of Calculators

a. The Calculator Market. In Germany, more than 50 types of calculators are sold, produced all over the world. There is only one German Manufacturer, Aristo in Hamburg. Almost every adult has at least one calculator. The prices vary from 15 DM ($\sim$ \$8) upwards.

b. Calculators in Schools. Except for experimental reasons, there are no calculators or other computational devices in grades 1-6 (7). In grades 8-13 (7-13), almost every student possesses or will possess by 1985 his or her own calculator (found by inquiries all over West Germany by Herget et al. (1978), 5 000 students; Meissner and Wollring (1978), 5 200 students; and Wynands (1978), 6 900 students).

c. General Assessment. The slide rule in the curriculum (from grade 7 upwards) will be replaced totally by the calculator (according to Herget, Meissner, and Wynands). Teachers and parents regard the calculator usually only as a calculation tool; therefore, calculators should not be used before or during developing computational skills. The official study of the Ministry of Education of Nordrhein-Westfalen also made this assumption about the usage of calculators in schools (FEoLL, 1977). All 11 Ministries of Education have established this opinion in official regulations: the calculator is only allowed from grade 8 (7) upwards.

d. The View of Specialists. The view of the calculator by specialists is like the general view of mathematics education:



Most of the specialists (research, projects, teachers, administration) emphasize (b); there are deficits in (a). A more balanced view about future necessities is given in the "Gesellschaft für Didaktik der Mathematik (GDM, 1978) or the "Institut für Didaktik der Mathematik" (Winkelmann, 1978).

2. Calculators in the Classroom

a. Grades 8-13. The calculator is used in different situations (Engel, 1978):

(1) to save time in calculation

(2) to solve problems with more realistic data

(3) to emphasize mathematical ideas more then computation

(4) to introduce new topics which need more computation

(5) to analyze sets of data

(6) to explore mathematical situations

(7) to run simple computer programs without a computer

(8) to renew the view of the structure of mathematics.

The calculator is allowed in tests whenever calculation is not a goal of the test. Usually the students (or parents) buy the calculator via a collective order of the school. There are no maintenance problems (warranty for at least one year), and no problems of introducing different types of calculators in the same classroom.

b. Grades 1-6 (7). Except for some experiments, the calculator is generally forbidden in these grades. The goal of the experiments is to gather experiences on how children react to the calculator and how we can stimulate skills and abilities in mental arithmetic and paper-and-pencil algorithms while using the calculator (Arens et al., 1978; Meissner, 1978).

3. Inservice Education

There is no obligatory inservice in Germany. Calculator inservice is offered mainly by congresses of associations of teachers or educators (like NCTM, NCSM, MAA, and so on) or by small meetings sponsored by the Ministries of Education. There are some new German books (Löthe and Müller, 1979; Sieber et al., 1978; Wynands and Wynands, 1978) on calculator usage in schools (grades 7-13), translations from American books, and the journals for mathematics education. Some journals devoted special issues to the topic "calculator" (MU, 1978; ZDM, 1978). Exchange of ideas also takes place by private correspondence (Baumann, TIM). Some national meetings were devoted only to the future of calculators in mathematics education (GDM, 1978; TIM, 1976).

4. Curriculum Development

Curriculum development in Germany usually happens as a result of preceding main trends in mathematics education. (Projects with public or

administrative sponsorships or funds to develop curriculum materials do not exist.) In correspondence with 1-d, we will have a substitution of the slide rule by the calculator and some new topics (see 2-a). But today there is no big sensibility for the problems concerning computational skills and abilities in correlation to an increasing usage of calculators.

5. Research

a. Grades 1-6 (7). The only research is done at Teacher Training Colleges, emphasizing view (a) (see 1-d): What will be the impact of calculators on mathematical and computational skills and abilities? Which are the consequences for a future curriculum? The findings of Meissner (1978; 1979) indicate:

(1) The calculator helps successfully to train basic facts (addition facts, multiplication tables, order of magnitude, monotonicity, intuitive nests of intervals, intuitive concept of limit).

(2) There are different modes of a number sense (digital and analog) and therefore different kinds of computation (syntactical and semantical). The calculator stresses "digital" and "syntactical". Applications of mathematics need interpretations of numbers ("analog" and "semantical").

(3) The calculator helps to train a function sense. The basic idea is the "one-way principle", which involves systematic trial and error. (The one-way principle is an additional stage in the spiral approach.)

(4) The calculator seems to be no help for low achievers in elementary grades. They do not know why to push which key and therefore make many mistakes.

b. Grades 7-13. There is some research at Teaching Training Colleges and universities. Topics are listed in 2-a. The calculator seems to be helpful for low achievers concerning the four basic operations and the percentage key.

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III. Synthesis of National Reports

As one reads the reports in the previous section, one is struck by the similarity of the issues and concerns about hand-held calculators that are being faced in the 16 countries. Some divergence is found, however, in how the issues are being resolved in various countries.

1. Trends, predictions, and prevailing opinions about curricular implications of calculators

"New ideas have often met with public resistance," as Szetela notes (p. 19). Calculators were quickly acquired and are in common use by scientists, engineers, economists, and other professionals; almost every household has one in some countries (e.g., Switzerland, the United States). Yet, although calculators have been in some schools since 1973 (e.g., in the United Kingdom), many of the reports indicate that mathematics teachers may be reluctant to use them. [They generally have been welcomed by teachers of other subject matter, especially the sciences, where calculators are often considered a part of the student's expected equipment (e.g., in Australia), and in non-academic courses (e.g., in Japan)]. Moreover, there is increasing resistance as grade level decreases; that is, primary teachers are most resistant to their use, while secondary teachers have accepted them to a greater extent, especially as a calculational tool, and university teachers allow their use with almost no concern (except in some instances where they ignore calculators, as was noted in Brazil). A quotation from the United Kingdom expresses the picture at the lower elementary level:

> ... the attitude of primary school staff to the calculator ranges from an enthusiastic welcome through passive tolerance to hostility. (Bell et al., 1978 cited on p. 56)

Fielker adds:

> While some are willing to look into the possibilities, the majority are worried that arithmetical skills will be forgotten. (p. 56)

Cheung notes that, in Hong Kong,

> In the primary schools, the use of the calculator is not formally and widely accepted in the classroom because both parents and teachers fear that the calculator might become a crutch to children of this age range and thus impair the learning of the basic computational facts and skills. (p. 25)

Shimada adds that, in Japan,

> Generally speaking, it seems that many teachers are reluctant to introduce calculators in their classes, partially because of their belief that at the elementary school level teachers must concentrate on fundamentals and ... students must master basic skills in computation without special aids, and partially because of monetary problems involved and a fear of new change. (pp. 36-37)

Also from Japan comes the comment that at the secondary level, teachers are "theory-oriented" rather than "practice-oriented" and therefore keep numerical complexity at a minimum; thus, they do not feel the need to use calculators.

In West Germany, it is similarly felt that calculators should not be used before or during the development of computational skills. The calculator is allowed only after grade 7 or 8 in the official regulations of all 11 ministries of education.

Szetela notes that in Canada

> School boards are keenly aware of the objections and concerns of parents toward calculators and hesitate to pursue an uncharted course utilizing calculators without strong public support. (p. 19)

In the United Kingdom, Fielker reports that

> Furthermore, some employers have been vociferous in their demands for arithmetic without calculators. It is sometimes difficult to persuade teachers that calculators are not detrimental to arithmetical health, in spite of continuing evidence in the U.K. and from abroad that the use of calculators improves ability at computation. (p. 56)

And it is noted that in Canada, it is believed that "Calculators should be used to supplement rather than supplant the study of necessary computational skills" (p. 21).

In countries like Thailand, the issues have "not been seriously considered" yet, since calculators are less available than in some other countries. New Zealand provides another instance in which there is little argument about the use of calculators:

> Little concern has been expressed by teachers, parents, or the community either for or against the use of calculators ... There has been no strong pressure to introduce calculators into the curriculum, nor to exclude them. (p. 40)

Use in schools tends to be on an informal basis, depending on the initiative of individual teachers within an individual school.

Nevertheless, a statement from Australia is indicative of the status in most countries:

> During 1975 and 1976, both individual teachers and education systems began to realize that they would have to come to terms with the calculator, and that process of adjustment is still underway. (p. 5)

Over and over, similar arguments are raised for using or not using calculators at various schools levels (but especially at early levels). Thus, among the points favoring the use of calculators as a teaching-learning device are:

- attainment of more time for "genuine mathematical content" including new content, and for teaching concepts
- emphasis on problem-solving strategies and mathematical ideas rather than routine calculations
- use of more practical examples and problems with realistic data
- support for heuristic and algorithmic processes
- increase in motivation
- enhancement of discovery learning and exploration
- attainment of speed and accuracy, with relief from tedious calculation
- enhancement of understanding
- lessening of the need for memorization

Most telling of all is the comment that, since their role in society is increasing, students should learn how to use calculators.

The points cited for not using calculators involve:

- fear of dependence on calculators as a crutch, which will "damage the development of children, making them less capable of intellectual achievement"
- tendency to fail to criticize calculator results
- non-availability to all students, since they cost too much for some (thus enhancing the gap between "haves" and "have-nots")
- creation of a false impression that mathematics is computation
- insufficient research on long-term effects
- reduction of achievement in basic computational skills
- decrease in understanding of computational algorithms
- lessening of ability to think
- lessening of ability to memorize
- reduction of motivation to learn computational skills and mathematical principles, or to think through mathematical problems

It is obvious that fear of loss of computational skills with paper and pencil is the predominant concern.

2. Research activities with calculators

The amount of research evidence being accumulated on the effects of the use of calculators varies across countries. In some, there is little or no research activity (Australia, Austria, Hong Kong, Ireland, Japan, New Zealand, Switzerland, and Thailand seem to fit this category). In several others, a limited amount of research is being conducted by college or university faculty and/or graduate students, usually with the focus on the secondary school level or occasionally the upper elementary level (Belgium, Brazil, Canada, Israel, and West Germany appear to fit this category).

In the remaining three countries, the form of research is more extensive, but still varied. In the United Kingdom, the Durham Education Committee, the School Mathematics Project, and the Shell Centre for Mathematical Education have been most heavily involved. Experimentation has been largely exploratory and informal, with the emphasis on ascertaining what could be done with calculators and on the development of comparatively short curricular sequences, with formal data-comparison studies at a minimum. In Sweden, the activity has been organized in a somewhat comparable but more centrally controlled fashion. The first directives from the Board of Education came in 1975; this past year some trials started at various grade levels from 4 through 12. ARK (Analysis of the Consequences of Calculators) is coordinating a wide program of research and development, studying the effect of calculators as an aid for calculation, as an aid in changing the methods in the present curriculum, and as an aid in changing the content of the present curriculum.

In the United States, over 100 studies have been conducted, most independent of the others and most using an experimental design in which the achievement of calculator and non-calculator groups on various curricular topics or modes of instruction have been compared. Almost all such studies indicate either higher achievement or comparable achievement when calculators are used than when they are not used. A handful of studies has looked at learning-oriented quesstions, in an attempt to ascertain how learning of mathematical ideas (rather than merely achievement) can be improved with the use of calculators. In addition, less-formal curriculum development studies have been underway, to develop sequences for instruction at most grade levels. The majority of such work has concerned integration of the calculator into the existing curriculum; far less attention has (thus far)

been given to revising the curriculum to integrate calculators. This research and development work is proceeding at several levels, with university mathematics educators, supervisors of mathematics, and teachers collaborating in some attempts and working largely independently in others. While federal funding has supported some studies (including a number of grants directly to school systems), other work has proceeded solely because an individual (including many doctoral candidates) felt the need to pursue the topic and collect evidence.

Across countries, the overwhelming majority of the data -- from both formal experiments and informal experimentation -- has supported the conclusion that the use of calculators does not harm achievement scores (in particular, computational scores). From the few studies focusing on the point, there is indication, in fact, that use of calculators can promote computational skill achievement, as well as the learning of other mathematical ideas.

There is continuing need for informal research by teachers at the classroom level to establish and evaluate ways of using calculators to investigate both existing and new topics in the curriculum. Similarly, mathematics educators need to continue efforts to ascertain how the calculator can serve best as a tool to promote learning.

3. Instructional practices with calculators

The need for curriculum development is evident in the comments from several countries; for example, a comment from Austria indicates

> A main obstacle for intensifying the use of calculators is the fact that neither the curriculum of mathematics nor the schoolbooks are related in any way to the needs and possibilities of the calculator. (pp. 11-12)

The Australian reports adds:

> For the mathematics classes, there has been a more systematic consideration of how calculators might be used, not merely to carry out calculations ... but also to attack new types of problems, or old types of problems in new ways. (p. 6)

In the report from Ireland, it is noted that

> Teaching methods and course content may need to be revised to take advantage of calculator techniques. (p. 29)

And the Canadian report points out that

> ... teachers would prefer to wait [to use calculators] until materials ... are written. (p. 21)

"Restrained enthusiasm" and a "lack of bold projects for implementation" are also noted (p. 23). There is need to incorporate additional work on such topics as estimation and approximation, significance of answers, mental arithmetic, rounding, and flow charting; the limitations of calculators also need to be taught.

In most countries, as the report from Belgium notes,

> There is still some quarreling going on between two groups, the one stimulating the use of the calculator only as a computational tool and the other willing to take more advantage of calculators as an instructional aid. (p. 13)

It seems fairly evident that, given the concern by parents and teachers about students learning paper-and-pencil computational algorithms, these will not rapidly disappear from the curriculum in most countries. Fielker notes that

> Even among the more enthusiastic schools, the calculator has been assimilated into existing curricula, and no one so far has altered the curriculum to take account of the calculator. However, there is enough development taking place to indicate the way things eventually should go. (p. 56)

He indicates that paper-and-pencil algorithms will persist as only part of an "armoury of techniques". Pupils will design their own algorithms, and the focus will be on the development of algorithms for calculators and computers. Thus, he writes:

> ... one questions whether ... written arithmetic is any longer necessary. ... What is required is an ability to check that answers are reasonable; hence a facility with "single digit" arithmetic, and a sense of the size of numbers to be expected in real situations [is needed]. (p. 57)

In Israel, similar concern is expressed for algorithmic thinking, but the focus is

> not to try to revolutionize the mathematical curriculum, but rather to modify it by putting emphasis on algorithms for solving meaningful problems and carrying them out to completion. (p. 31)

From Japan comes this comment:

> If we admit an assumption that calculators are always available in any classroom, then emphasis might be shifted from mastering a certain set of prescribed algorithms to developing various algorithms based on fundamental properties of number, and grading difficulty by number of digits in computation might become not so meaningful. (p. 38)

However, few textbooks have incorporated use of calculators.

Sweden is relatively advanced in curriculum development compared with most other countries. New curricular sequences integrating calculators are being tested. In West Germany, Brazil, Argentina, Israel, the United States, and the United Kingdom, there are some smaller-scale efforts to develop calculator-integrated curricula. While the Swiss report indicates that "changes in curricula are for the time being not necessary because of the use of calculators" (p. 47), curricular guides may include use of calculators as aids; such statements have also been included in many other countries. Thus, the official syllabus for New Zealand recommends the use of calculators, but only at Form 7 (for 17- and 18-year-old students). In Hong Kong, the new mathematics syllabus for secondary schools attempts to incorporate the use of calculators, including decreases in emphasis on some topics and the addition of several new topics. In most countries reporting recommendations, the use of calculators is suggested after grade 7 -- that is, after initial teaching of computational skills is completed and they have presumably been learned.

A matter of concern to many persons -- though at a lower level than the concern over use of calculators in elementary schools, associated with fears over loss of computational skills -- is the concern over their use on tests. The report from Ireland provides a particular illustration of this. Calculators were used on examinations in 1974 and 1975. Then:

> Public awareness of a possible social discrimination in the use of calculators in examinations was fanned into life by an article in one of the leading daily newspapers; the Minister of Education became worried, and calculators were banned from the public examinations in 1976. They have been banned since then . . . (pp. 28-29)

In Australia, school inspectors began in 1977 to recommend that students be permitted to use calculators on public examinations. By 1980, virtually all examining boards will permit the use of calculators on grade 12 examinations. From 1980 on, the calculator will also be allowed in the Hong Kong Certificate of Education examinations.

By 1978, four of eight boards administering the General Certificate of Education Examination in England were permitting use of calculators on Ordinary Level, and two others permitted them at A Level; the Scottish Board was permitting them in all examinations. However, they are not allowed on the English Certificate of Secondary Education examinations (and

therefore most schools have not used calculators with average and below-average pupils).

In New Zealand, on the other hand, some locally based regional examinations for low achievers in mathematics do incorporate the use of calculators, although they are not permitted in national school-level examinations. Calculators (including programmable types) are allowed in secondary-level examinations in Sweden, but not in grade 9. The policy in West Germany is that calculators are allowed on tests in grades 8-13 whenever calculation is not a goal of the test (calculators are not used below grades 7 or 8 in the instructional program).

In the United States, calculators are not allowed on standardized tests (because of their construction and norming), and most teachers do not allow their use on any mathematics tests. The College Entrance Examination Board is considering the need to modify existing tests or develop new tests on which calculators will be used, however. Their actions could have an impact both on other test developers and on the use of calculators in instruction.

4. Student outcomes, attitudes, and concerns about calculators

Students are generally positive about using calculators. Some teachers (in Belgium), however, reported that students quickly lose interest "when they realize that much thinking is involved in working with them" (p. 14). Whether for this reason or another, the initial high level of motivation that is usually attained when calculators are first introduced is rarely a lasting phenomenon. (After all, the calculator is a tool; consider the chalkboard: does it keep children excited day after day?)

It may well be, however, that low achievers who have continuously failed in mathematics may find that the calculator provides a means to help them succeed. And as the curriculum changes, some anxieties about mathematics may be relieved, causing a long-lasting motivational effect.

5. In-service activities on calculator use

Little cohesive planning of in-service activities for teachers, to help them place the calculator into perspective and develop strategies for using it effectively, was reported. Professional associations of teachers, local or national educational authorities, teachers' centres, and universities have shouldered the burden of sponsoring conferences, meetings, seminars,

workshops, short courses, and/or discussion groups. There has been little systematic planning for these, however: they seem to arise upon demand, with little attention devoted to creating a demand so that teachers will be prepared to cope with calculators (and other technological phenomena which could impact upon schools).

Articles have been published in journals in most (but not all) countries reporting, although the number of such publications, and of books, shows a wide variance from country to country. In the United States and West Germany, information centers provide an additional means of disseminating materials to teachers (and to others interested in the use of calculators).

As was noted in the Canadian report, the in-service activities are "not as widespread as needed" (p. 22) and "it can hardly be said that [calculator materials] are sought by a tidal wave of teachers" (p. 22).

6. General background on amount and type of use of calculators

Three generalizations about calculator use seem appropriate:

(a) The higher the age level, the more likely students are to own or have access to calculators.

(b) The higher the grade level, the more likely that calculators are used in schools.

(c) Four-function calculators are most used in elementary schools, scientific calculators in secondary schools, and programmable calculators by the college years. Calculators with algebraic logic appear to be most widely used (especially in pre-college years), probably because they are more widely available at lower prices.

Calculators are either bought by individual pupils (sometimes through school-organized plans) or by schools. In Japan, the Ministry of Education subsidizes one-half the cost of equipping schools with calculators, according to a schedule, and limited federal funds are available in some other countries (e.g., the United States) for purchasing calculators.

Concluding Comment

The terms "fluid situation" and "cautious approach" appear in the reports, and would seem to characterize the situation in many countries. In at least one country, New Zealand, "Other issues in mathematics education

... appear to be of greater priority" (p. 41).

The Australian report notes that the need to preserve a reasonable arithmetical facility will continue to be argued. But, as Fielker notes:

> Unless we effect the necessary changes in educational attitudes, it could be that the classroom will be the only place where arithmetic is done by hand! (p. 58)

IV. Report of the Working Group*

The working group began with each person commenting on some of the ideas presented in the reports from the 16 countries, or providing additional information. Interwoven throughout the discussion was concern for the use of calculators as it has affected and might affect stability and change in the curriculum. In most countries, there have been no substantial curriculum development efforts to effect significant changes, although much has been published in which the calculator is used as a tool in the existing curriculum. Factors urging curricular stability (and even regression) have been led by the "back-to-the-basics" movement, plus fear of change by both teachers and parents, combined with fear of technology and concern over its increasing impact on our lives.

Following the preliminary discussion, the working group identified six questions of concern, several of which were then explored in the ensuing discussion:

1. How can the calculator be used as an effective instructional aid?
2. Calculators demand new attitudes toward mathematics, and hence changing goals and objectives for mathematics. How can these goals and objectives be stated and attitudes changed?
3. Recognizing the fact that calculators will be in universal use, even by small children, the school should take the lead in order to avoid harm. What types of harm are possible?
4. Teachers are afraid of having students use such powerful calculational aids: many teachers feel displaced from their role. How can teacher security in a new role be established?
5. To meet the need for exchange of information on calculator uses, how can an international network or clearinghouse be established?
6. What is the interface between calculators and computers?

1. Topics for calculator use

Some of the topics for which the use of calculators should be explored were identified, and pedagogical concerns were interwoven with the dis-

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* The working group met as one phase of the International Conference on Comparative Studies of Mathematics Curricula held in Osnabrück, Federal Republic of Germany, in January 1980.

cussion of this content. The hope was expressed that an expanded list, with examples, could be developed, and published for used by both teachers and researchers.

a. Elementary level topics

- Counting: the calculator can serve as a tool to count by 1s, 2s, 5s, 7s, etc., to form any number.
- Place value: again, the calculator can be used as a tool to explain the decimal values of the system through such examples as $2 + 3 = \square$, $20 + 30 = \square$, $200 + 300 = \square$.
- Negative numbers: these arise at the early primary level as, for instance, in the subtraction of $3 - 7 = \square$.
- Order and magnitude of numbers: these lead to the development of number concepts.
- Number theory: more numbers and ideas can be presented to develop number concepts.
- Meaning of operations: the calculator knows a set of numbers, and when two numbers are keyed, the calculator gives another number: $a,b \longrightarrow (a+b)$. This changes the meaning of operations.
- Properties: better understanding can be developed.
- Four operations developed simultaneously: instances where the student could use all four operations will arise, and therefore decisions on when and how to teach them need to be made.
- Order of operations
- Inverse operations (including their use for checking).
- Division: this can be taught as repeated subtraction.
- Fractions: the importance of operations with fractions is likely to decrease.
- Decimals: their importance is likely to increase; they can be introduced earlier, before operations with fractions.
- Algorithms: emphasis can be on a sequence of button pushing, with flow charting and iterative techniques explored.
- Functions: ideas and properties can be observed.
- Approximation and estimation: meaningfulness of what is done and of answers is of prime concern.
- Mental arithmetic: this is a vital component of all curricula, and imperative when using calculators.

- Equation-solving: the use of variables and of the guess/test strategy can be explanded.
- Problem solving: realistic problems with realistic data can be solved.
- Probability and statistics
- Logic: logical circuits of calculators can be explored.
- Gaming strategies
- Characteristics of the calculator: how the calculator processes, rounds, etc., can be explored, probably as a component of another topic such as approximation.
- Exploratory activities (e.g., with negative bases).
- Understanding: understanding can be developed through doing many examples, therefore building different levels of understanding.

Can some trends of change in curriculum be predicted? The working group accepted the reality that the existing curriculum will not change rapidly because of the availability of calculators. Yet the child has acquired a power of calculation never before known. What can be offered to this child today? What are the immediate and long-range implications for teachers and for the curriculum? Change must proceed from these questions as curriculum is redeveloped. With calculators, some mathematical ideas can be taught earlier and more quickly. Moreover, the curriculum can be redesigned with a central focus on functions and algorithmic learning and processing at the elementary level, rather than with the current focus on computation. Thus, curriculum changers must consider more than the evident capability of moving topics or speeding up the teaching of topics: they must consider the implications of having readily available calculational power. And they must consider not merely curricular changes, but changes in teacher knowledge and behaviors.

b. Secondary level topics

- Functions: global aspects as well as local aspects must be considered.
- Polynomial, exponential, and trignometric functions: the presentation of each needs to be reorganized, because the reasons for teaching them have changed (e.g., logarithms); various types of equations never used in the past can be used now (e.g.,

iterative); and, in fact, the focus can shift to iterative procedures. Therefore, students can solve rather complicated problems.

- Approximation: realistic number ideas, using precise and approximate mathematics, can be presented.
- Graphing: more and better graphing of functions is needed -- since it is easier to locate many points and plot, students can better develop meaningful concepts and methods.
- Probability and statistics
- Computational mathematics: this can replace artificial mathematics, with students using heuristic procedures.
- Limits
- Simulations (e.g., population change).
- Error analysis (i.e., the capability of the calculator to develop and accumulate errors can be explored).
- Forming problems: ways of doing this, as well as grouping and presenting them, should be taught.
- Use of calculators: included should be consideration of the limitations of calculators; variations among calculators; and finding new procedures if limited by a display of 8-10 digits.

The use of calculators means that the user must understand mathematics better, not less; for example, one must understand how to simplify in order to avoid overflow. There is a possibility of using very sophisticated machines, and solving problems by pushing a few buttons. Therefore, there is a need for a great deal of theoretical background, and mathematics becomes not easier, but more difficult. The curriculum may move from an emphasis on algebra to mathematical analysis. But algebraic algorithms will not all disappear (e.g., finding the square root, taught as an algorithm and not as just a key, will remain, since calculators provide an easy means to teach algorithmic procedures).

New branches of mathematics can be introduced with calculators, including algorithmic processing and linear programming. But we should be wary of overemphasizing numerical procedures. Geometry should not be neglected; to understand what is going on in mathematical analysis, certain geometric intuitions are necessary.

2. Possible harm from calculator use

There are actually two categories of harm pertaining to the calculator: (1) misuse (e.g., reading the display from right to left) and (2) abuse (e.g., using the calculator instead of learning the basic facts). We have a responsibility to teach students to use calculators wisely to avoid both types of harm. Among the factors which may be harmful are:

- limited number of digits in the display, leading to rounding differences.
- extensive stress on algorithms: with simple sequences, pushing buttons can mean rote learning of a set of procedures without thinking about the meaning.
- loss of facility with number, including loss of basic facts or paper-and-pencil skills.
- decreasing use of manipulative materials -- there is danger that children will compute using numbers for which they have developed no understanding.
- overreliance on the acceptability of results from the calculator. It was noted, however, that children do not think or know they are incorrect when they do not use calculators. Mental computation needs to be taught so they can know when the calculator is wrong, or when entries have been made incorrectly.
- use of calculators must depend on the objective of instruction: it is ridiculous to use them for some objectives.

The general public also sees other dangers and says it is harmful to use calculators because they will:

- become a crutch -- the child won't always have a calculator and thus will become handicapped.
- result in loss of ability to make calculations. [In such comments, no distinction is made between two types of calculations -- some should or must be automatic (e.g., when basic facts are used), while others are used rarely by most persons and therefore the time spent learning them could be spent in better ways (e.g., long division could better be done by machine).]
- interfere with the learning of concepts: the fact that concepts are not always learned well without calculators, or that calculators can help to build concepts, is ignored.

We need to take account of each possible harm and try to avoid it, as well as alert teachers and public to it. Strategically, we need to talk about possible harm from calculators, even though there may be none. And even if there is harm, calculators will not go away. We must teach children to cope with them.

3. Teacher reactions

Every educational change is feared by many teachers (and by many others as well). We need to help them to become open-minded toward calculators. It is obvious that many teachers are not prepared to use calculators, expecially those at the elementary level. They do not have the mathematical background, and they tend to have anxiety about machines. Workshops are an essential phase in helping to prepare teachers. How in-service kits are used by small groups of teachers in Quebec, Canada, was described by Gaulin. The teachers learn how to use their own calculators; many instances where it is appropriate to use calculators in the classroom, plus some counterexamples; good pedagogical reasons for using calculators; and the mathematics essential for making intelligent use of calculators.

Teachers also need a long-term support system as they use calculators. The role of responsive leadership is vital.

As machines become more sophisticated and as curriculum changes, a massive in-service task faces mathematics educators: the problem should not be minimized. We do not want a "new math" disaster: we must not paint too rosy a picture.

4. International information exchange

The functions of the Calculator Information Center in collecting and disseminating information on calculator uses in the United States were briefly described. There is a need for such a center to serve as an international clearinghouse, so that an international network can be established.

5. Implications of computer use

It is difficult to pinpoint the border between computers and calculators. Thus, computer literacy is much more difficult to define today, and must include calculators. The size of the computer (even though small)

makes it different from the calculator, however: the calculator is personal, the computer much less so. With the calculator, no computing language is needed. However, the language for computers is getting simpler, while communicating with a calculator is becoming more sophisticated. Therefore, eventually we will have to develop the ability to communicate with machines from the early school years.

The calculator can be used by every individual. The computer, however, divides adults into three categories: (1) most are only affected by computers; (2) some work with computers to affect others; (3) some manage computers and decide what their effects will be. We must reach those in category 1 who will never work with computers. If one has done some programming, one has a different feeling about computers: some feel that one must program in order to understand computers. But at least we need to develop computer literacy materials to develop awareness, attitudes, and alertness to the problems presented by computers.

To set up a curriculum is a slow process -- technology will move much more quickly. Catastrophe is therefore possible: we can get too specific and have curricular materials appropriate for yesterday's technology. Some point out, however, that there is a parallel between printing and computing technology: concern was once felt about the effect books would have on education and people, too. We can reflect too much concern over the inevitable. There is danger of calculators being perceived not as an instrument but as a goal.

The teacher's role is likely to be forced to become less authoritarian. The teacher must become more communicative with children -- and technology can help us to make these changes. The "inevitable", in other words, will probably force change, slowly but inexorably, upon the school.

V. Selected References

Approximately 150 references are included in the list which follows. An attempt was made to select items which are "better" in quality and which are representative of the scope of the types of materials being published on hand-held calculators. While some non-U.S. references are included, the majority were published in the U.S. This may reflect not only the resources available to the compiler (Suydam), but also the fact that so much material is published in the U.S. Suggestions for additions -- or deletions -- to the listing are welcomed.

In lieu of annotation, a simple three-categoy coding scheme has been used:

A - references on instructional activities and curricular suggestions

B - background information on issues, trends, and more general curricular suggestions

R - research reports

The code represents the major emphasis of the reference: other categories may also be appropriate for a particular document.

For additional information on any of the documents, two reference centers (and perhaps others) can supply it:

(1) The Calculator Information Center, 1200 Chambers Road, Columbus, Ohio 43212, U.S.A. (Marilyn N. Suydam, Director)

(2) Projekt TIM 5/12 - Taschenrechner im Mathematikunterricht, Pädagogische Hochschule, Fliednerstrasse 21, D-4400 Münster, West Germany (Hartwig Meissner, Director)

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